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Vol. 27 : No. 174 MARCH, 1960 Price 2/6

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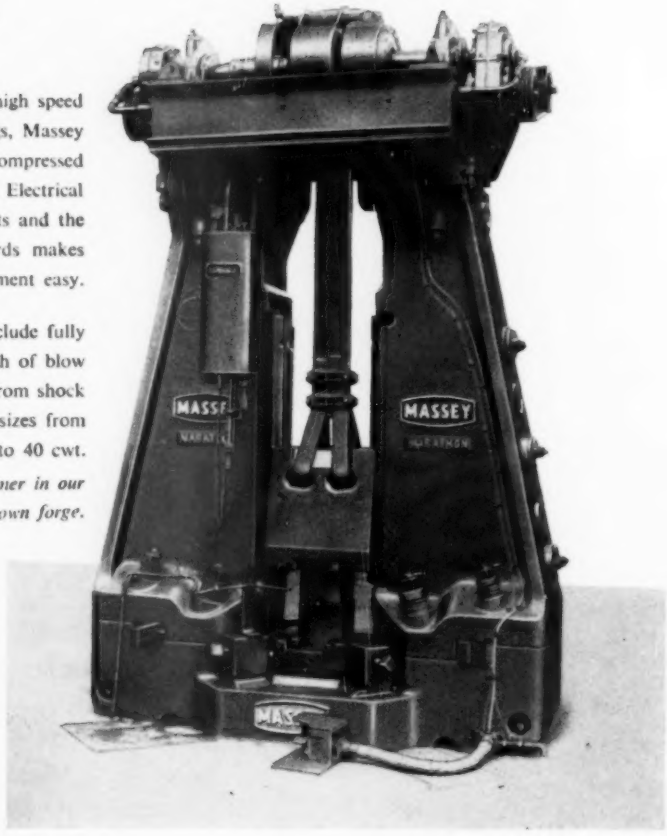

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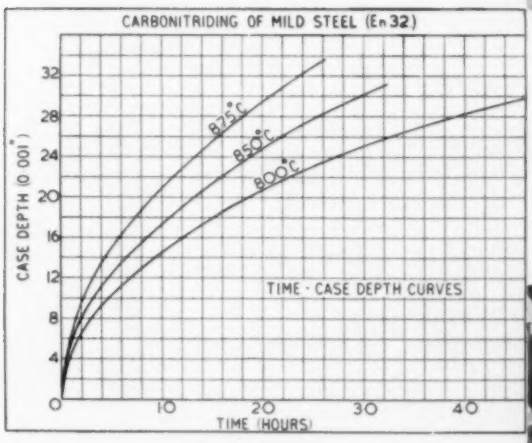

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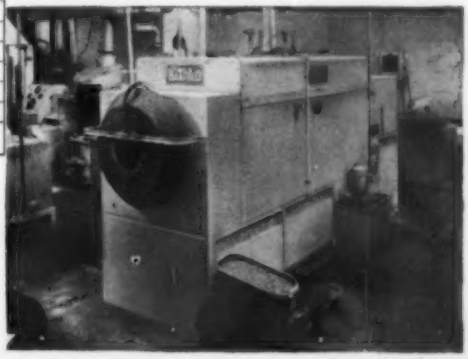

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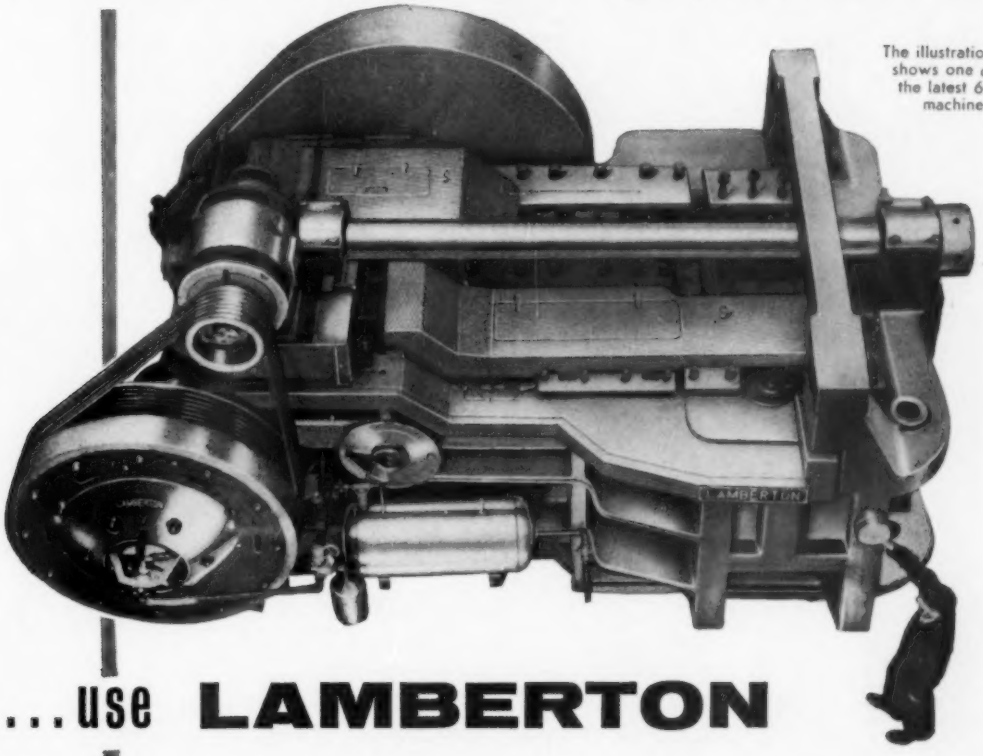

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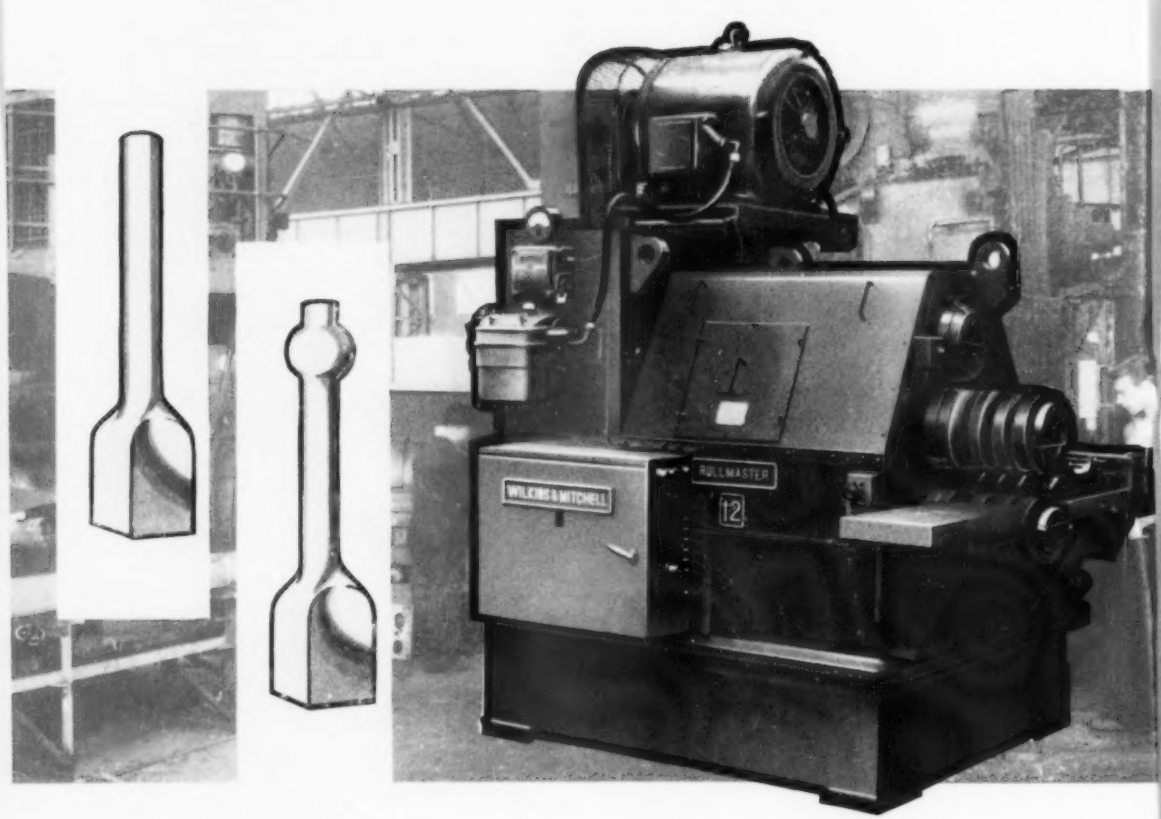

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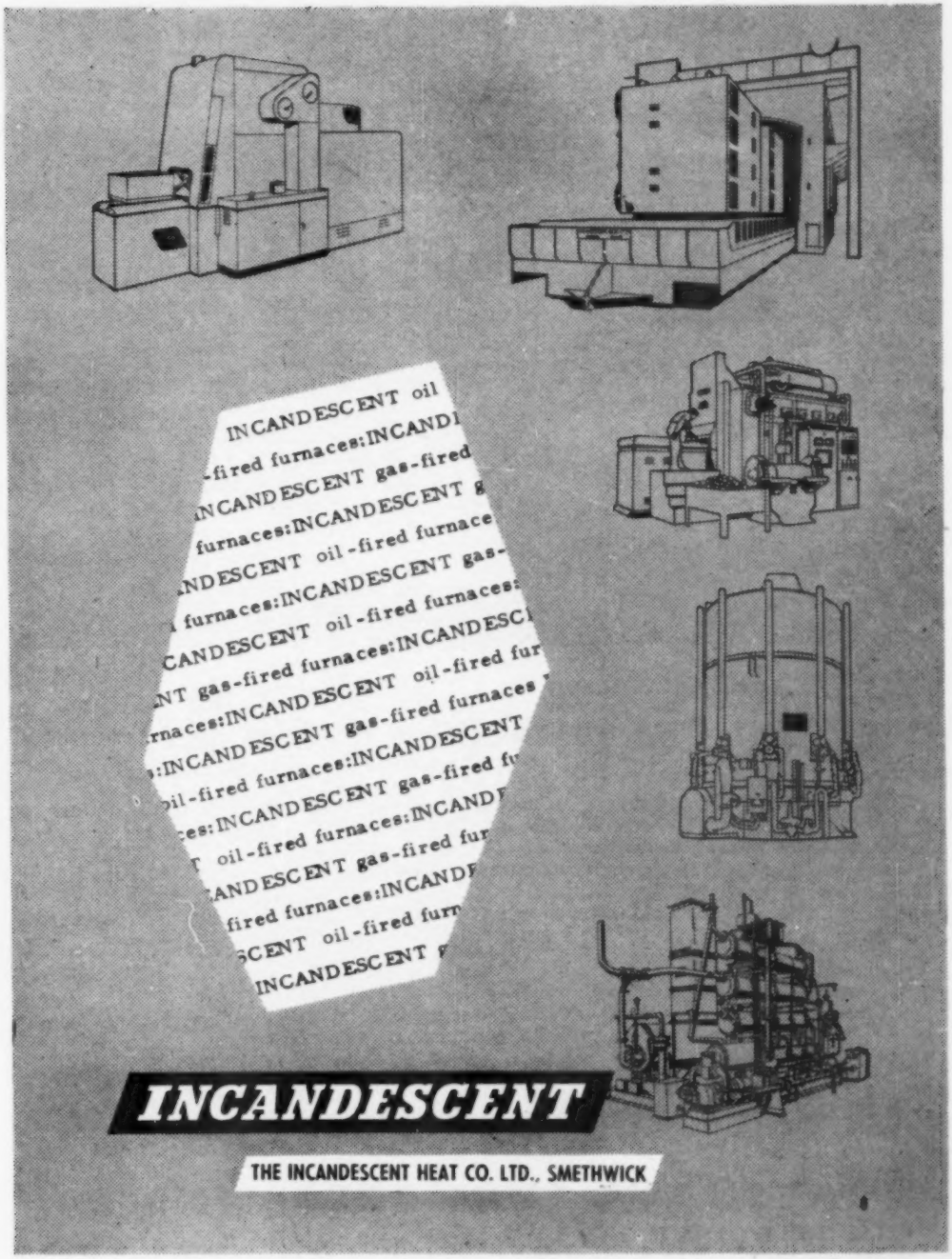
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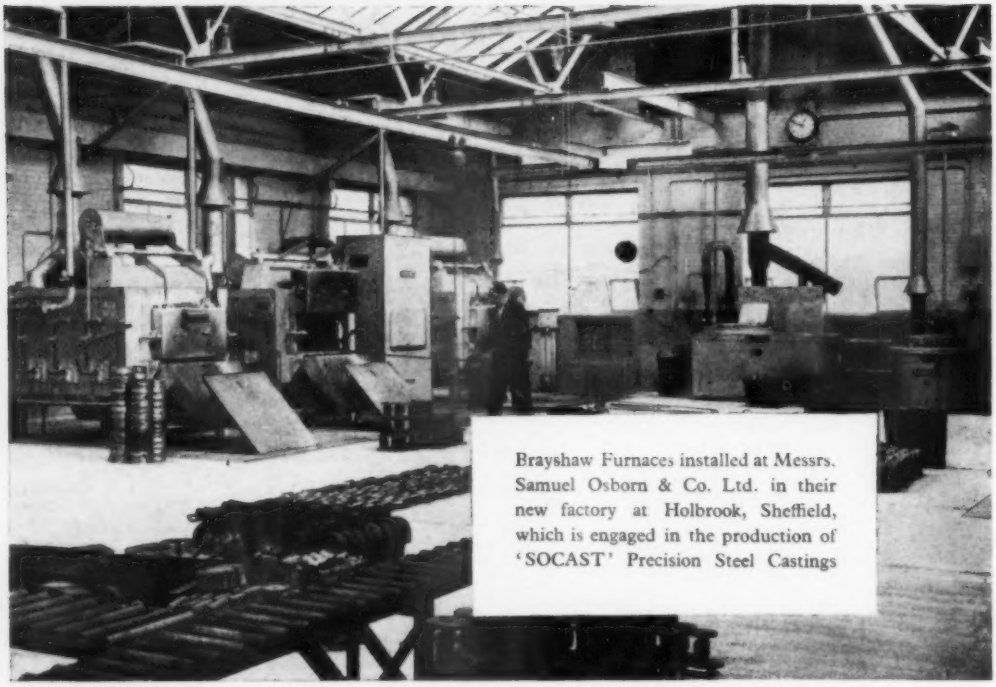

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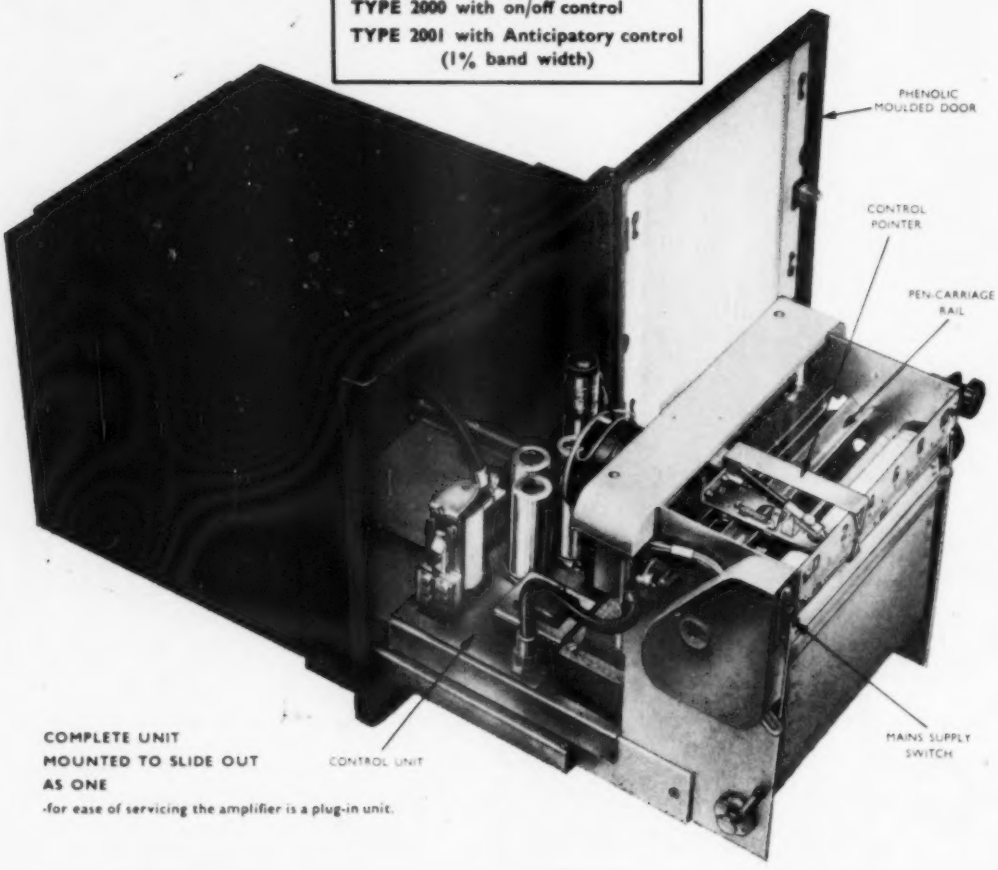

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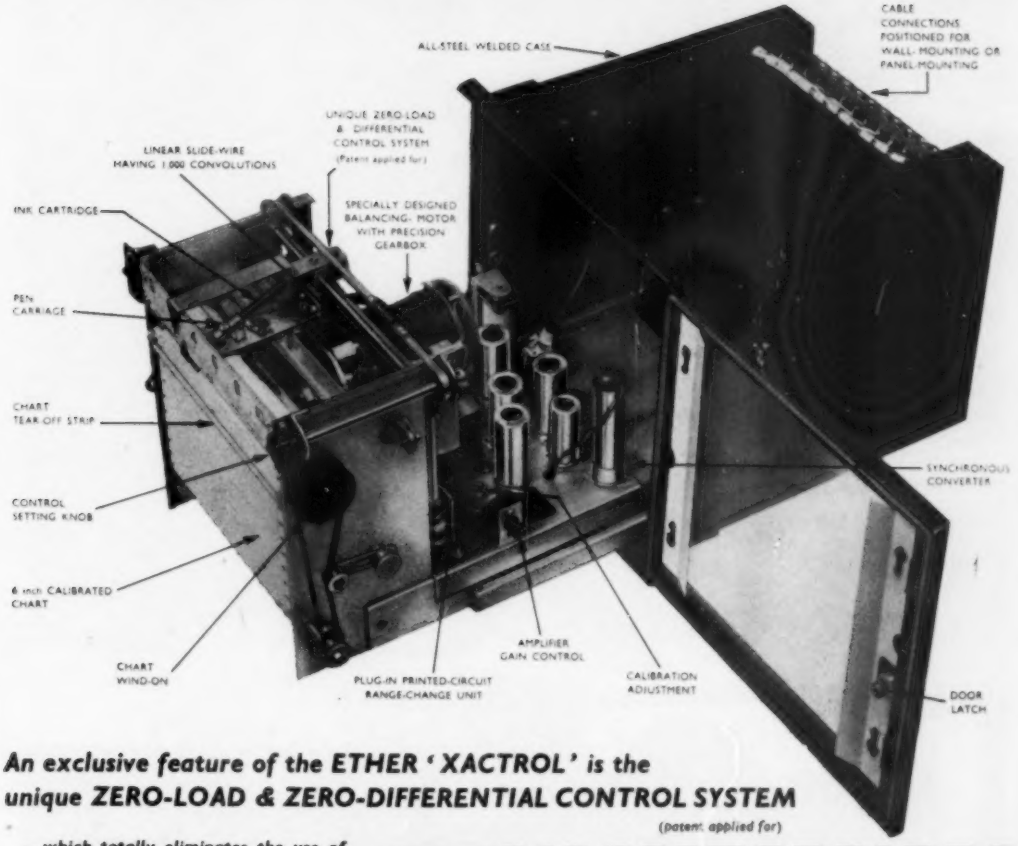

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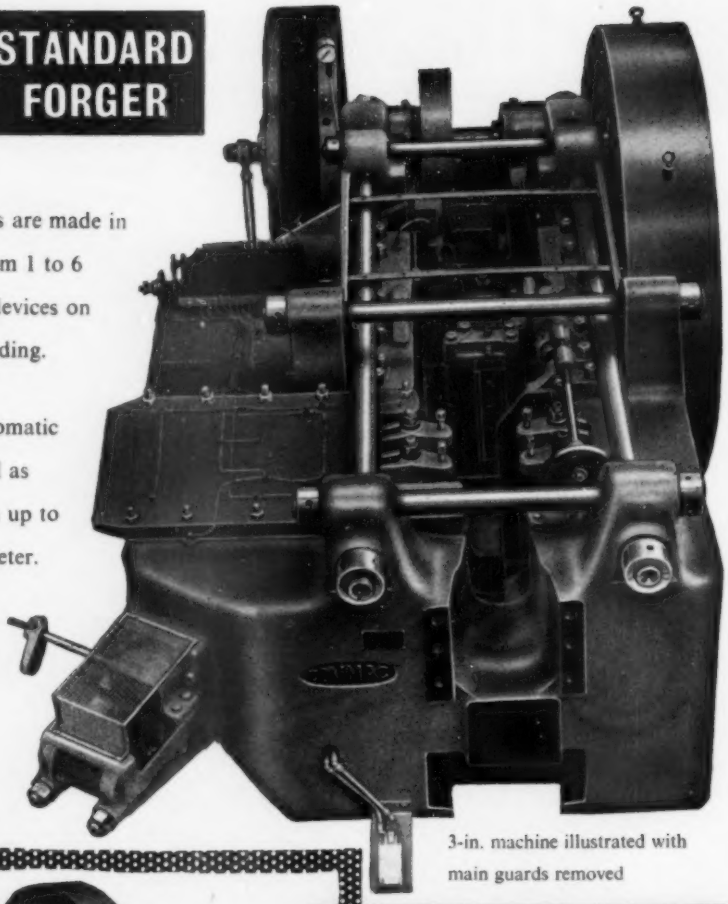
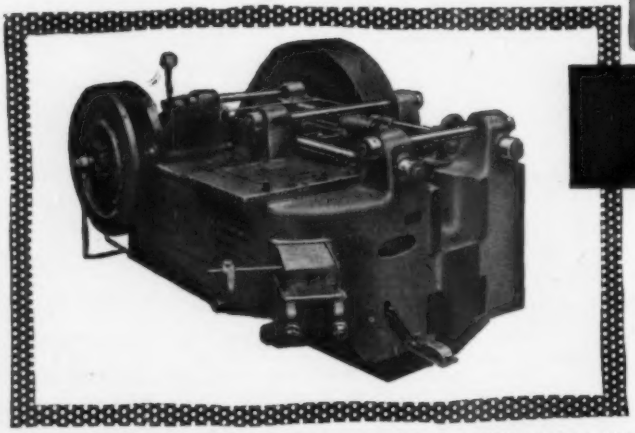


3-in. machine illustrated with main guards removed



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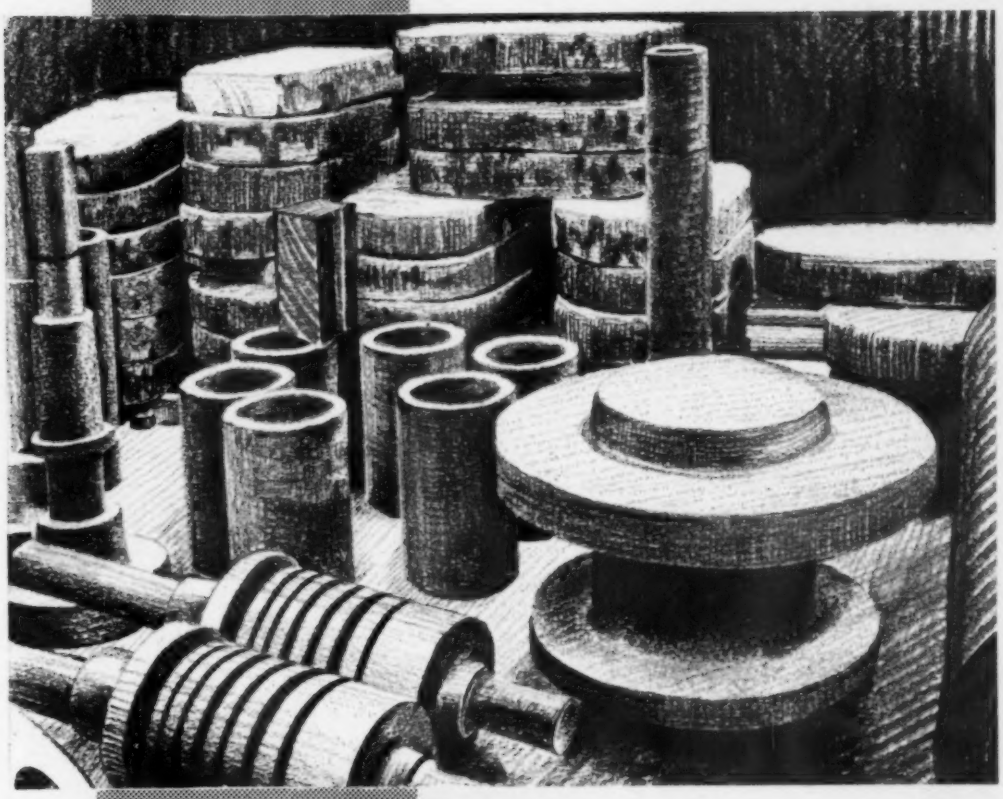

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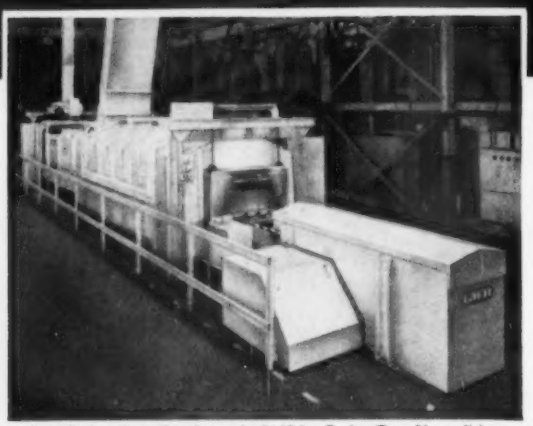

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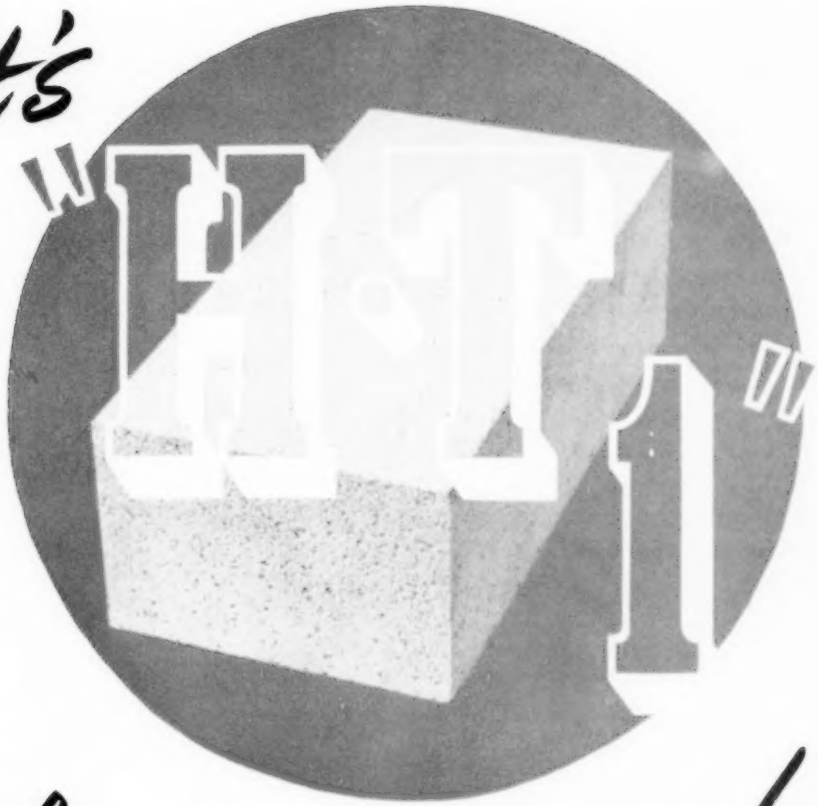

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March 1960

Vol 27, No 174

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and Drop Forging

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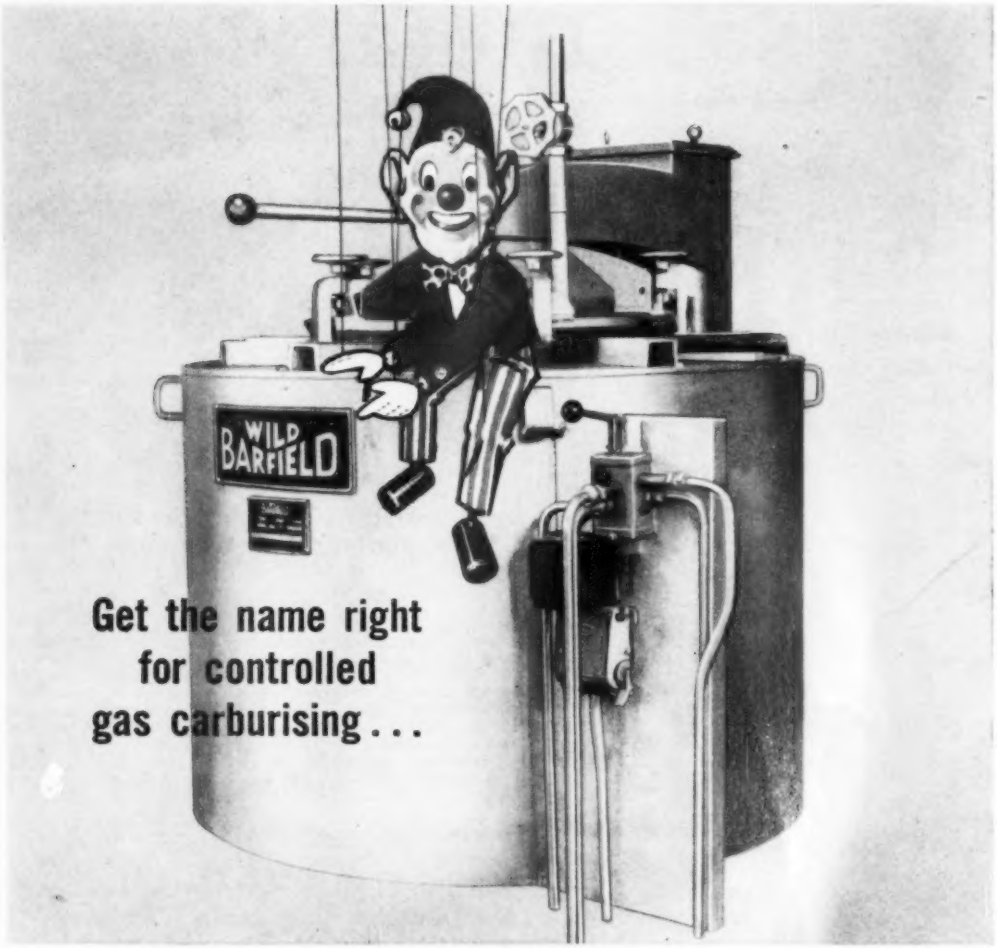

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W.B. 101

Competition

IT is an observable fact that a measure of competition is necessary in all things if stagnation is to be avoided. There can be little doubt that the increasing threat of foreign exports during recent years has stimulated our own industries to initiate changes in production methods which might otherwise have remained only dreams. An excellent example of this is in steelmaking, where the supremacy of the open-hearth furnace was scarcely challenged in this country until the pressure of continental production insisted on notice being taken of the newer oxygen processes.

All this can be seen as a sign of healthy life, but it also follows that all branches of industry must regard themselves as committed to the struggle. Certainly, there is no room for a complacent reliance on an assured future on the basis of past achievements. An industry investing much money and resources in research and development may well start expanding and suddenly appear as a competitor in new fields.

An example of this in action, of particular interest to the drop-forging industry, was demonstrated at the recent Engineering Materials and Design Exhibition at Earls Court, London. A collection of over 50 outstanding castings, selected from firms throughout Britain by the British Steel Founders' Association, were displayed. The intention was to show designers how steel castings have actually replaced components previously fabricated or forged at a saving in cost or weight and reduced maintenance. This impressive display clearly showed the formidable progress made in castings in recent years, and suggests that a study of the industry's research and development activities might well be a worth-while safeguard.

This jockeying for position is by no means confined to alternative processes but applies with equal force to alternative materials. In the U.S.A., the du Pont company is challenging metals with its most recent plastic which it recommends as a substitute for metal die-castings. It is claimed that 75% of the market for the new plastic, ' Delrin,' will be in fields now supplied by steel, brass, aluminium and zinc. It is already replacing brass in water taps, being used for motor car door handles and is even in one application replacing spring steel. Another use for plastics is being suggested by Esso Research and Engineering. Pipes made of glass-reinforced plastic are under development for oil and gas use; they will cost more than steel pipes but lower installation costs and greater resistance to corrosion are believed to offset the difference.

Among the metals, aluminium as a relative newcomer is the most aggressive. Competition between aluminium and steel will probably be very limited for many years owing to the great difference in price, although considerable invasion of the canning industry is possible in the near future. In the U.S.A., use of aluminium in motor cars increased from 5 lb. per car in 1955 to 56 lb. by 1959, and a further increase to 250 lb. per car is speculated for 1970. The use of aluminium in the engine of the Chevrolet small car is a major invasion of that field.

The traditional metals, copper, nickel, lead, tin and zinc, are all striving to maintain their positions in the face of aluminium expansion. In the electrical field aluminium-covered cable is gaining ground on copper, while extrusion sheathing of cable with aluminium seems a possible alternative to lead. In this connection it is interesting to note that the Aluminium Company of America has recently bought two wire-making plants with the intention of converting them from copper to aluminium.

Whatever the outcome in any particular instance of competition between processes and materials it seems certain that the future pattern will be a dynamic one. Like Alice in Looking Glass World we have to run faster and faster to stay in the same place.

Giant dies for hot forging

E. G. DONALDSON, B.Sc.

A special press for shaping heavy steel plates, the largest and most powerful of its type in Europe, has been in use since 1957 at the Darlington works of Whessoe Ltd. It has been used for the forming of plates for spherical pressure vessels required for nuclear power stations as well as other applications. The plates for the pressure reactor vessel at London's first nuclear power station at Bradwell, Essex, were shaped on this press, as were the plates for the reactor pressure vessel now under construction at Latina, Italy The author is with the International Meehanite Metal Co. Ltd.

WHESSOE LTD., one of the eight member companies of the Nuclear Power Plant Co. Ltd., has had the task of fabricating large reactor vessels. Nuclear power stations call for curved plates of exceptional size, thickness and strength, and the press installed at the Darlington works is able to shape the largest plates which the British steel industry can now produce, with a substantial margin for future development. The press and auxiliary plant at an expenditure of £500,000 has placed Britain in the forefront of the race for nuclear power station orders from overseas countries. The plates for the two spherical reactor vessels at Bradwell, which are 66 ft. 6 in. in internal diameter, vary in thickness from 3 in. to 4 in., and weigh up to 8 tons each.

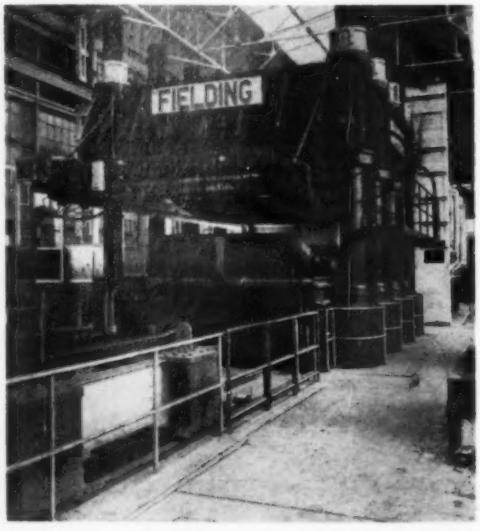
Plant layout

The press, which was specially designed and built by Fielding & Platt Ltd., of Gloucester, has an unusually long upward stroke, exerting a pressure of 4,500 tons. It is operated hydraulically, and has automatic controls. Fig. 1 shows a general view of the press.

Erected in a common longitudinal line with the press are the other necessary items of equipment. On one side there is the plate-heating furnace designed and made by Gibbons Bros. Ltd., of Dudley, which is capable of heating 20-ton plates to over 1,000°C. by town's gas firing. On the other side of the press there is the charging machine, again specially designed and built by the same company.

Operation

The charging machine (fig. 2) is loaded with the plate to be pressed while stationed outside the press. The plate is passed by the charging machine through the press and into the open door of the furnace on four arms. These arms are then dropped and withdrawn. The plate is carefully heated up to temperatures approaching 1,000°C. When the desired temperature is obtained, the charging machine arms lift the plate from the hearth and draw it on to the machine. The machine then returns on its track until the hot plate is located centrally with the press blocks. The plate is then lifted clear of the machine by means of the ejector rams in the base of the press so that the machine can be completely withdrawn. The press



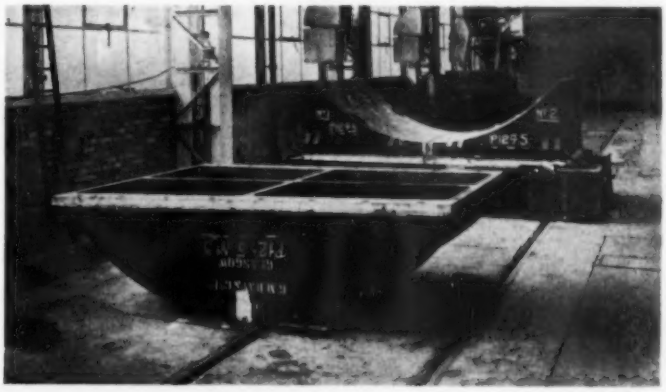
1 *The 4,500-ton press for shaping steel plates up to 4 in. thick at temperatures of over 900° C.*

table and the bottom block bearing the steel plate are raised up to the top stationary block and pressure is applied. The bottom block and plate are then lowered and the plate left on the block until cooled. When the plate is cool enough to retain its shape, it is once more lifted by the ejector rams. Then the charging machine carries a special cradle under the plate which is lowered on to this cradle and withdrawn.

Selection of die material

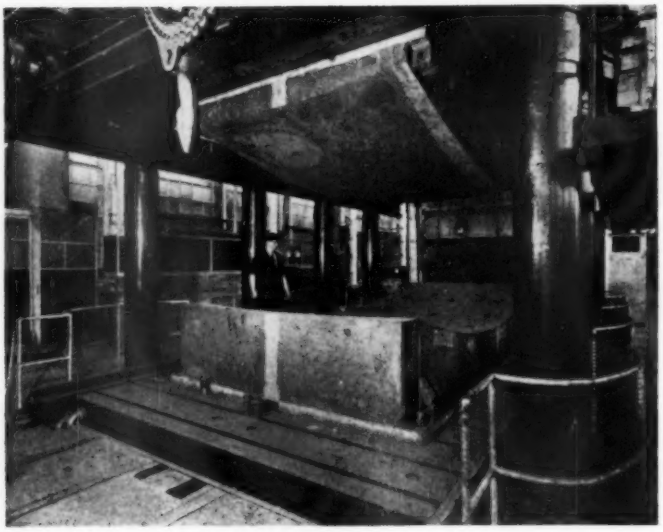
The dies used in this hot-forming operation must be particularly stable and strong at the operating temperature. The temperature of the bottom block is estimated to reach 800°C., and the block is soaked for a considerable period around this temperature. The dies must, therefore, be sufficiently strong at this temperature to withstand the applied stress, and they must be able to withstand the thermal shock and the thermal gradients developed during repeated usage.

The metal selected for these dies was Meehanite Type GC, an unalloyed ferrous-cast material with a minimum tensile strength of 18 ton/sq. in., and a compression strength of 70 ton/sq. in. This relatively inexpensive material is in this application withstanding repeated punishment in loading and thermal stresses which few other materials could endure. As a cast-to-form die, requiring no machining on the working face, the economies in its use are considerable. Clyde Tubes Ltd. have been using hot-forging dies in Type GM Meehanite for



3 *Close-up of smaller die set showing details of construction. The bottom die is composed of two separate castings. The clay-thickness method of checking clearances is shown by the lumps of clay on this die*

2 *Detail of the dies with charging machine visible in background, and set of smaller dies on the left*



4 The size of the castings may be seen from the man's figure in background. The foundations for the press required 2,400 tons of clay and silt to be removed for an excavation 45 ft. deep

many years for forging ⅜ in. wall tube at temperatures of 750–850° C. in a 1,000-ton press. These castings produced by Cameron & Robertson Ltd. have given excellent service, and have replaced alloy steel dies.

All the blocks used by Whessoe Ltd. were produced by G. M. Hay, of Glasgow, who specialize in large castings up to 40 tons in weight. The larger dies have been cast in sections. The blocks used for the Bradwell reactor plates with overall dimensions of 21 ft. by 8 ft. were cast in three sections; that is, the top block is composed of three sections and so is the bottom block. Together they total about 72 tons. The method of assembly is visible in fig. 2. The castings were sound and possessed good surface finish, casting section varying from 4 to 6 in.

Die performance

One significant fact is that these die blocks are not machined on the working surfaces. They are fettled and cleaned up by the foundry, and checked for accuracy on the press by the clay thickness method as shown in fig. 3. A certain amount of chipping and grinding was required on high spots, but after arranging for expansion allowances at the joints the final rectification was obtained by accurate machining of the bases of the dies where they are bolted down on to the press table. Fig. 4 shows an all-round view of the assembly and gives an idea of the size of these castings.

The first set of the cast-to-shape die blocks are still in service, having pressed 600 plates. Performance is considered entirely satisfactory. Shortly after start of use, cracks appeared around the edges of the ejector ram ports on the bottom block. These travelled slightly, and then stopped. They have had no effect on performance, and it would appear that the cracks are primarily due to stress concentrations at the edges of the ports which can be prevented by minor design modifications. There is no evidence of heat crazing on either the upper or lower blocks.

Kelvin Hughes and Curtiss-Wright agreement

An agreement has been concluded between Kelvin & Hughes Ltd. and the Curtiss-Wright Corp. of America for the exclusive right to manufacture and sell the non-destructive testing equipment of the other partner. This includes instruments for the inspection and measurement of materials, and equipment employing ultrasonic techniques in all industrial fields.

The agreement covers certain defined territories. Kelvin Hughes will represent both interests in the U.K., the Commonwealth (except Canada) and Europe, and Curtiss-Wright in the U.S.A. and Northern America. Each party to the agreement will offer full sales and service facilities on the joint range of equipment.

School for welders

More than 800 welding students, many of them from overseas, pass through the welding school of British Oxygen Gases Ltd. at Cricklewood, London, each year. Forming part of the company's sales technical service department, it is the largest of several welding schools operated by British Oxygen Gases. It can train 48 students in oxy-acetylene processes and 12 in Argonarc welding at any one time.

Courses range from two weeks' oxy-acetylene welding instruction on light-gauge sheet and tube, to a general and maintenance syllabus lasting up to eight weeks.

Application of electron microscopy

Thin films and their use in metallurgy

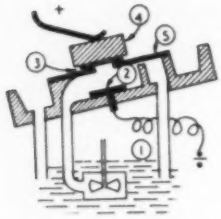
ADRIEN SAULNIER AND PAUL MIRAND

Direct examination under the electron microscope of thin metal films has the advantage of making the diffraction and microdiffraction diagrams of the electrons correspond with the micrographic images. However, the technique of preparing very thin films has proved both long and difficult. Moreover, it could only be used in exceptional cases for alloys, and it did, in fact, remain the special province of highly specialized laboratories. The authors, of the Research and Physical Test Laboratory of the Pechiney Company at Chambéry, have developed a quick and simple method, applicable to most metals and alloys. They reported their work in 'La Revue de l'Aluminium,' June, 1959, and have specially revised this account in English for METAL TREATMENT

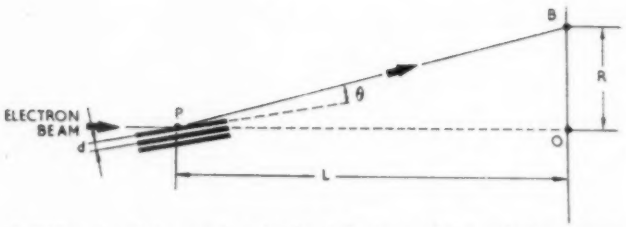
SIMPLE ENUMERATION of some of the metals, such as germanium, silicon, titanium, zirconium, uranium, tantalum, beryllium, and niobium, which will now constitute an appreciable part, along with their many alloys, in the tonnage and business turnover of metal products, will give an idea of the complexity of the problems which are set to works and laboratories in the development of techniques in the field of electronics, aircraft, missiles, astronautics and nuclear power. In order to respond to these new requirements, empiricism, which still remains in some of the older works, is having to give way to a more scientific conception of planned metallurgy. Metallurgical physicists have formed themselves into schools and their coordinated work is beginning to bear fruit in the conception of fundamental phenomena. The study of oxidization, for example, has been completely revised and it will be possible in future to start from a scientific basis in determining the metals or alloys which are capable of showing the best behaviour in the presence of gases at high temperatures. Experimental work still remains essential, but it is greatly lightened and speeded up by prior clearance of undergrowth which theory now makes possible. Similarly, as regards mechanical properties, the dislocation theory and the vacancies theory provide solid bases for the development of new alloys or for the adaptation of standard alloys for use at high temperatures, under irradiation or in contact with special products.

In order that the theories developed by the physicists may prove fertile, they must first run the gamut of the laboratories before penetrating progressively into the workshops. This important role of assimilating, adapting and checking, which falls on the industrial laboratories, means that their equipment has to be increased and that their methods have to be constantly improved. It is for that reason that, during the last ten years, more and more laboratories have installed electron microscopes. The benefit which has been gained from them is well known to the readers of this journal. Profound study of the fundamental part played by sub-microscopic precipitates and of the sequences of precipitation during structural hardening has enabled a solution to be found of problems of brittleness in parts during hot-working and also of wear of tools in certain kinds of delicate machining. The mechanism of sensitivity to inter-crystalline corrosion in other types of alloys has been elucidated and this has led to the development of de-sensitizing treatments or of inhibiting additions. In the case of new metals and alloys, a knowledge of the sequence of phases and of their morphology has greatly facilitated the choice of compositions and of heat treatments for specified purposes, and even the study under the electronic microscope of the standard modes of transformation, disproportionate as these may appear, *a priori*, in forging for instance, by comparison with the unit of measurement (of the order of 1μ), has not failed to have immediate repercussions on manufacturing methods.

But hardly has the electron microscope proved its



1 *Device for preparing thin metal films by electrolytic polishing*
(1) *Electrolyte*
(2) *Electrolytic cell*
(3) *Sample*
(4) *Backing piece of metal*
(5) *Diaphragm*



2 *Diffraction of electrons by a family of P planes with a reticular distance d parallel to the electron beam and perpendicular to the plane of the diagram*

usefulness by the results it gives than it finds itself already out of date in the face of new demands. It is no longer a question of being able to see clusters of a few hundred atoms but of studying reticular defects of atomic sizes, whether they be linear (dislocations) or point defects (vacancies), the fundamental role of which is now well established. Such defects are well outside the limit of resolution of the usual replica which is several tens of Ångströms (1 Å. = 10^{-8} cm. = 1×10^{-7} mm. The aluminium lattice parameter is 4·04 Å.). They are even beyond the resolving power of the best electron microscopes (8–10 Å.), but experiments, and later calculation, have shown that they can be made visible by secondary effects which are produced during the transit of the electronic beam through the crystalline specimen.

Great interest is therefore attached to the preparation of thin metallic films transparent to electrons, directly observable in the microscope. It will be seen later that these metallic preparations also allow of diffraction diagrams being recorded, and, consequently, of structures being analysed, thus bringing an inestimable help to interpretation, which previously relied solely on morphology for the replica images.

Methods of preparing thin metallic films

In order to be transparent to electrons, the metal films must be prepared with a thickness not exceeding a few hundred Ångströms, that is to say, a few hundredths of a micron. Metal films complying with this condition have been made during recent years by evaporation in vacuum, by solidification from the liquid state or by electrolytic solution followed by ionic bombardment.

The evaporation method (Germer, Goldstaub and Michel, Trillat, Pashley and others) produces thin films of which the chief difficulty is that they possess properties noticeably different from those of the bulk metals. For instance, it would be an illusion to take the behaviour of such films during heat treatment as being similar to that of industrial products, since the evolutions are much more rapid in the thin films, and, even probably, of a different nature.

The preparation of thin films starting from the liquid state, with the help of an ingenious device (Takahashi), has produced results in so far as eutectics are concerned. But it cannot be used in a general way, as there would be a danger of coming up against a similar difficulty as that encountered in the evaporation method.

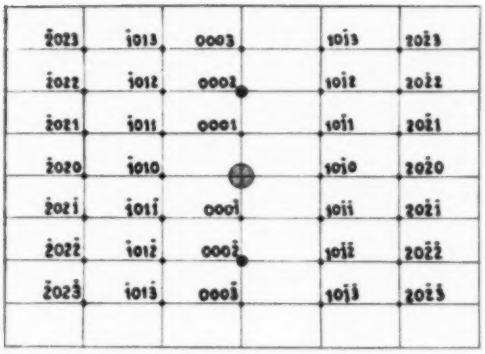
Electrolytic solution (Heidenreich) followed by ionic bombardment (Castaing) is much preferable since it allows of thin films being prepared from objects which have previously been heat treated in the mass. Unfortunately, it is very long and necessitates complex apparatus and delicate handling.

As a matter of fact, though these methods have been usefully employed in the research field,* they are not adapted to the needs of works' laboratories, owing to their limitations, to their lack of general applicability and to the difficulties in carrying them out, for the works have to apply their tests and their controls to very large systematic programmes, involving complex alloys and a great number of specimens.

A new method (1957) developed by the research department of the Compagnie Pechiney, at Chambéry, allows of quick preparation of specimens of a thickness suitable for electron micrography, starting from the mass metal or alloy, without the troublesome preferential dissolution of the phases present, and without mechanical or thermal upset, and this is done by using only the apparatus normally used for electrolytic polishing, which most metallurgical laboratories already have.

The first stage of preparation is mechanical reduction to a thickness of a few hundreds of a millimetre, care being taken to avoid severe cold-working and excessive heating. This technique is

*Cf. *J. Inst. Met.*, August, 1959, Hirsch, *Metallurgical Reviews*, 1959, 4, 14.



3 *Section parallel to the faces of the hexagonal prism* $(10\bar{1}0)$ *of the reciprocal lattice of α titanium. This section forms the theoretical diffraction diagram and should be compared to the actual diffraction pattern in fig.* 7

well known, seeing that it is used in micro-radiography. The prepared specimen is then placed at the anode of an automatic electrolytic polishing apparatus, being fixed on a diagram of about 5 mm. dia. against which it is held by means of a metal counterweight (fig. 1). The electrolyte is the one which is normally used for polishing the metal or alloy in question. Two or three alternating polishings of 5–10 sec. each are made on each face of the specimen to reduce its thickness and to remove the surface layers work-hardened by the mechanical thickness reducing process. Then a final polishing is done for a longer period of 20 sec., during which the specimen is pierced whilst some small fragments are carried by the electrolyte into the tank. These fragments are collected and washed in the usual manner. They have a thickness of a few hundred Ångströms and are sufficiently regular over surfaces of many tens of microns. They give good electronic images.

The contrast of these images is due, not to excess thickness on the specimen, as is the case with replica images, but mainly to the fact that the different areas diffract the electrons in a different manner according to their crystalline network, their orientation, etc.

In the case of micrographic examination, the diffracted rays are cut out by a diaphragm. An area of the specimen, which has caused an intense diffraction, will then be characterized by a lack of light, that is to say, by a clear space on the photographic plate. But in the present electronic microscopes it is equally possible, by cutting out the lens diaphragm, to record the diffraction pattern produced by the passage of the electrons through the crystalline network of the specimen.

A metal section, thinned down by the above-mentioned method, and placed under the microscope, allows of the successive recording of images to the desired magnification and of the corresponding diffraction pattern. Image and pattern are closely complementary, since contrast in the image is precisely tied up with diffraction.

Electron diffraction

Diffraction of electrons by crystalline gratings shows considerable analogy with diffraction by X-rays. Fig. 2 shows the diffraction of a pencil beam by a set of planes P, with a reticular distance d and perpendicular to the image plane. One can imagine that this phenomenon can be represented by saying that there is selective reflection for an angle θ, determined by the equation

$$\lambda = 2\,d \sin\theta \qquad (1)$$

λ being the wavelength associated with the electron beam.

However, diffraction of electrons is characterized by extremely low values of wavelengths λ, which, according to equation (1), means that the θ angles are also very small. With L as the distance between the object and the photographic plate and R the distance OB between the centre of the negative and the diffraction spot (fig. 2), we can write:

$$2\theta = \frac{R}{L}$$

(*Note.*—λ is given by the De Broglie formula $\lambda = \sqrt{\frac{150}{V}}$ with necessary correction for relativity, V being the acceleration voltage. When $V = 100$ kV. we get $\lambda = 0{\cdot}035$ Å. To give a comparison, the wavelength of Kα rays of copper is equal to $1{\cdot}54$ Å.)

Equation (1) then becomes $\lambda = d\frac{R}{L}$, or again,

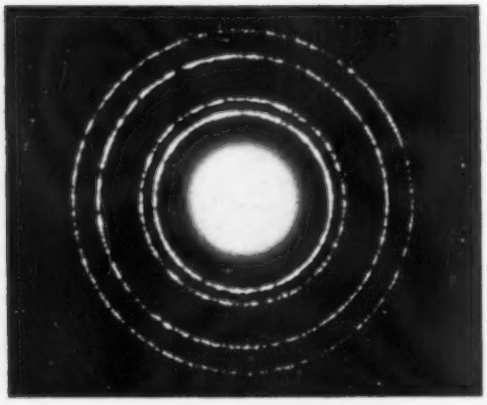
$$R = k\frac{1}{d} \qquad (2)$$

in which k is an experimental constant which will be known as the 'enlargement factor.'

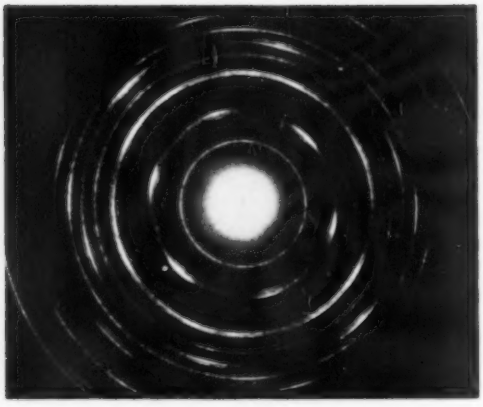
Then, the distance R from a diffraction spot to the centre of the print is inversely proportional to the reticular distance d of the diffracting planes.

Then again, when θ is very small, only the reticular planes which are practically parallel to the electronic beam, can give diffraction spots. It can also be deduced from this that the segment OB is perpendicular to the system of diffracting planes.

In short, the diffraction image B of a set of planes P, with a reticular distance d, parallel to the electronic pencil-beam, is built up by taking a segment OB, starting from a point of origin O



4 (*a*)



4 (*b*)

4 *Generalized diffraction of thinned specimens (a) Al, (b) Ti 2% Cu*

(centre of print), perpendicular to the planes P and of length $OB = k\frac{1}{d}$, k being an experimental constant.

The preceding build-up can be generalized: by the term ' reciprocal network ' is meant, for a given actual network, a network constructed by taking from a point of origin O perpendiculars to the various sets of reticular planes of the real network and by marking off, on these perpendiculars, segments inversely equal to the reticular distances of the corresponding planes.

From what has been said above the two fundamental properties of the reciprocal lattice are as follows:

5 *Al-Cu 4% quenched and heat treated 21 days at 350° C. θ' and θ phases. Original ×80,000, reduced to ×75,000 on reproduction*

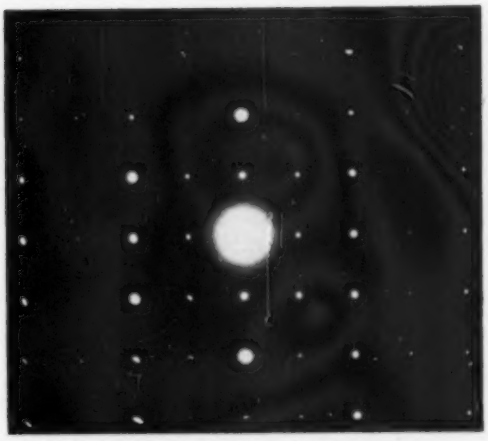
(1) Each node of the reciprocal network represents a set of planes of the real network.

(2) The electronic diffraction patterns form plane sections of the reciprocal network, perpendicular to the direction of the electron beam and enlarged by the factor k. In our experiments on microdiffraction, factor k was equal to 42×10^{-7}, which means to say that the microdiffraction patterns, reproduced in this paper, represent plane sections of the reciprocal lattices enlarged 420 million times.

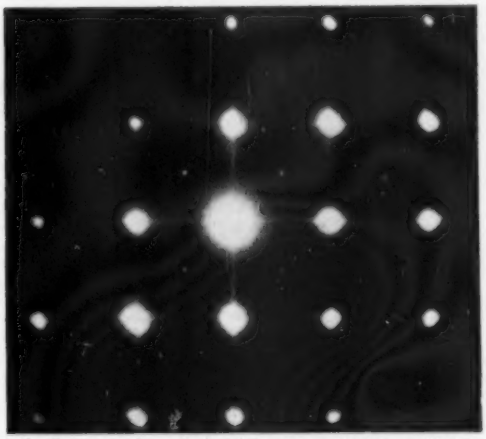
Metals generally have simple lattices, cubic or hexagonal. Construction of the reciprocal lattice presents no difficulty. It is shown that the reciprocal lattice of a face-centred cubic lattice with a parameter a, is a cubic-centred lattice with a parameter of $\frac{2}{a}$ (and *vice versa*). The reciprocal lattice of

6 *Ti-Al* 15% *quenched from* 900°C. *Section* (0001)α. ×75,000, *reduced from* ×90,000

7 *Ti-Al* 6%. *Section* (01$\bar{1}$0). *Micro-diffraction*



8 *Ti-Al* 15%. *Section* (01$\bar{1}$0). *Additional superstructure spots*



9 *Cu-Be* 2%. *Quenched and heat treated* 24 *h. at* 190°C. *Section* (001). *Diffusion streaks parallel to* <001>

a hexagonal lattice is a hexagonal lattice. Fig. 3 shows, as an example, a section parallel to the faces of the hexagonal prism (index 01$\bar{1}$0) in an α titanium reciprocal lattice. The different nodes of this reciprocal lattice are indexed as a function of the systems of reticular planes which they represent and it will be seen that this theoretical pattern coincides exactly with the pattern actually recorded by diffraction of the electrons, as shown on fig. 7.

APPLICATIONS

Generalized diffraction pattern

It is evidently possible to record from specimens, thinned by the method we have described, general electronic diffraction diagrams, that is to say, based on a large number of microcrystals. These patterns are ring-shaped, as in the X-ray diagrams of Debye-Scherrer, and they supply information of the same kind on the structure and orientation of the phases in question. Figs. 4 (*a*) and 4 (*b*) give two examples of this application, to pure aluminium in the one instance (this print serving as a standard for the determination of the diffraction constants) and to a Ti-2% Cu alloy in the other instance.

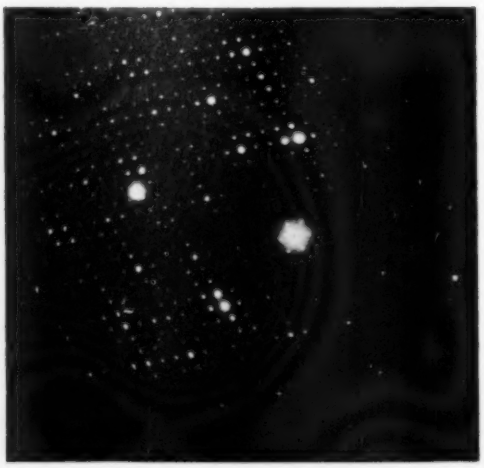
However, it is quite easy to obtain, with modern microscopes, microbeams, and to examine, both by micrography and by microdiffraction, areas with a diameter of the order of the micron. As the

10 *Cu-Be 2%. Quenched and heat treated 1 h. 30 min. at 190° C. Precipitates 100 Å. size (beginning of hardening).* ×75,000, *reduced from* ×80,000

12 *Single crystal of β-Al_3Mg_2 constituent in a cast Al-Mg 15% alloy*

11 BELOW *Cu-Be 2%. β→α+γ transformation after quenching and ageing*

13 BELOW *β-Al_3Mg_2 constituent. Section* $(1\bar{1}0)$



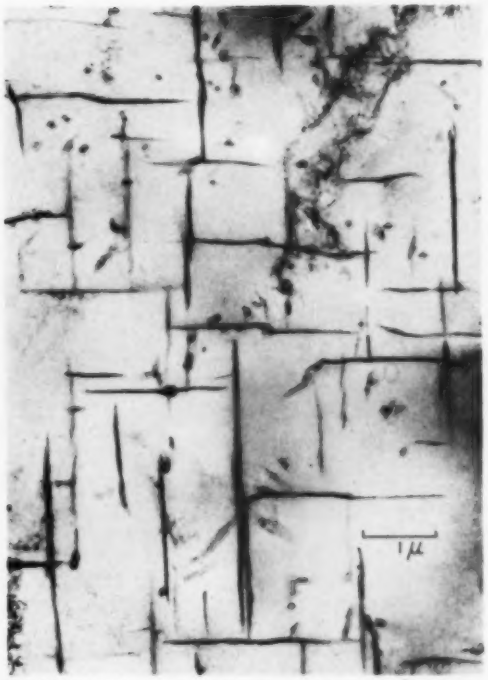
14 *High resolution micrograph of a β-Al_2Mg_2 constituent. Lattice planes* (220). ×2,100,000

dimensions of crystals of a polycrystal aggregate are generally larger than the micron, it is apparent that this technique will make it possible to study monocrystals. This is the most interesting, as it is also the most difficult, avenue for electronic micrography and it is in this direction that efforts are now being made to develop, and it is to this that the following examples will refer.

Aluminium-copper alloys

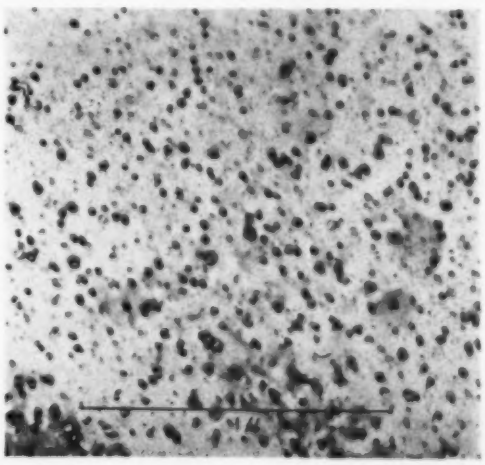
In an Al-Cu alloy supersaturated after quenching, reheating produces precipitation of the θ″ phase or of the θ′ phase, according to the temperature and length of the heat treatment.

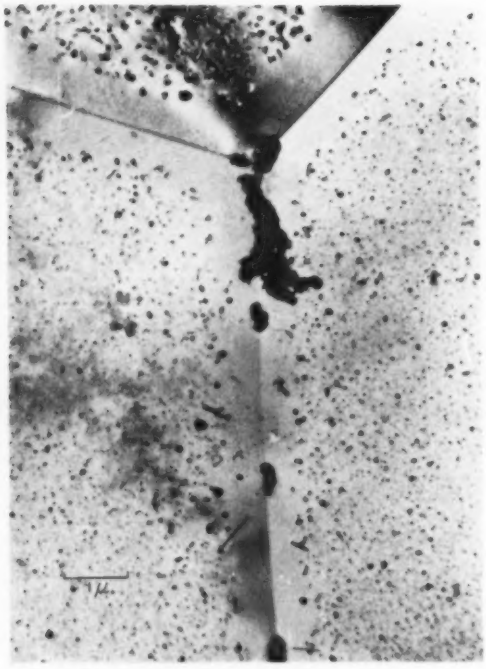
Castaing has shown that these phases can be made evident in micrographs of thin sections and that diffraction patterns of electrons contribute valuable support in the study of structural hardening. For the purpose of cross-checking between these methods a high-purity Al-Cu (4%) alloy was quenched at 525°C. and then heated for 21 days



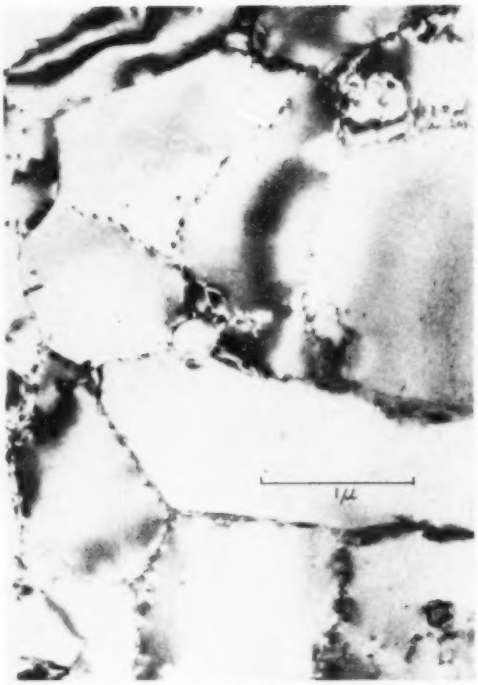
15 *Al-Mg* 10%. *Quenched and heat treated* 1 *month at* 120°*C. Section* (001). *Precipitation of the* β′ *phase.* ×18,000, *reduced to* ×10,000

16 BELOW *Al-Si* 1·2%. *Quenched and aged* 2 *h. at room temperature. Precipitates of vacancies resulting in dislocation loops.* ×80,000, *reduced to* ×48,000





17 *Al-Si* 1·2%. *Quenched and aged* 3 *min. at* 350°C. *Thin section of* 3 *grains. Precipitation of Si particles.* ×16,000, *reduced to* ×9,600



18 *Al-Mn* 1%. *Cold worked. Section* (001). *Substructure in a monocrystal of the* α *phase. Some spheroidal* Al_6Mn *constituent included.* ×40,000, *reduced to* ×24,000

at 150°C. (max. hardening). It was then thinned by means of the E2 bath of the Disa-electropol at a tension of 65 volts.

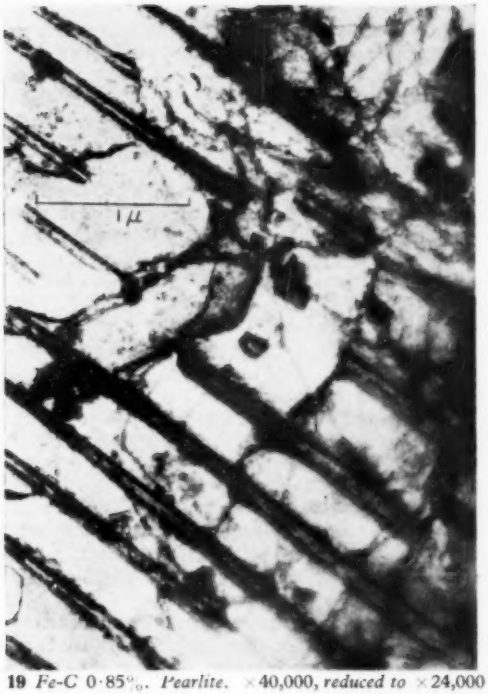
The micrograph, fig. 5, shows the θ′ and some θ″ platelets.

Titanium and its alloys

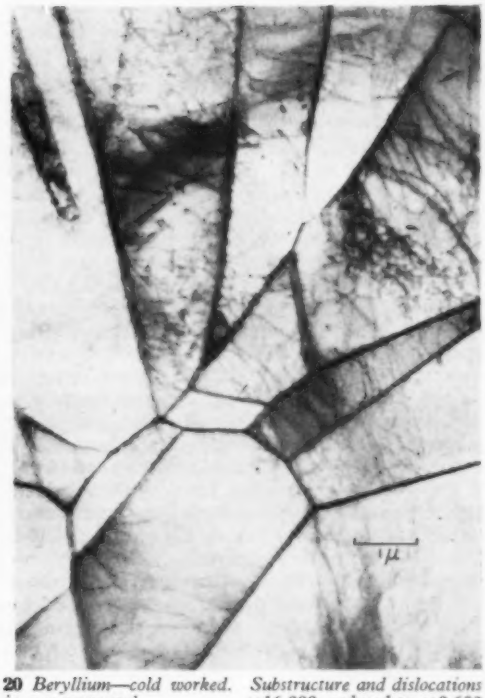
Our method of thinning down has been applied up to now in many investigations into titanium and its alloys, for which the A3 bath is used at 45 volts. Micrographs and microdiffractions of sections have enabled an interpretation being made of changes in mechanical characteristics recorded during annealing of cold-worked sheets, and of going deeper into the mechanisms of recovery and of recrystallization. It has been possible to show that it is recovery which is the fundamental process and that the idea of recrystallization, which depends to a large extent on the criterion used to define it, loses much of the significance which is usually attached to it.

In a study of Ti-Al alloys it has been possible to link up the embrittlement, which appears when the aluminium content exceeds 8%, with the appearance of a superstructure, that is to say, of an order (a category) between the atoms of titanium and the atoms of aluminium, in the solid α solution.

The embrittling platelets, with a thickness of 20–50 Å., are identifiable by direct micrography (fig. 6). The microdiffraction patterns allow of their structure and composition being defined. Fig. 7, for instance, shows the pattern of microdiffraction of a non-brittle alloy. It is, indeed, a section $(10\bar{1}0)$ of the disordered α solid solution (which can be compared with the theoretical diagram of fig. 3). If the Al content increases, the alloy becomes brittle, at the same time as an order is set up between the titanium atoms and the aluminium atoms, which is shown by the appearance of supplementary spots in the diffraction pattern (fig. 8). Comparison of figs. 7 and 8 is made easier by the fact that the sections are in the same orientation. Here is to be found one of the fundamental advantages of this method of thinning down. Owing to the easiness of carrying it out, it allows of a quick examination being made of a



19 *Fe-C 0·85%. Pearlite.* ×40,000, *reduced to* ×24,000



20 *Beryllium—cold worked. Substructure and dislocations in a monocrystal.* ×16,000, *reduced to* ×9,600

large number of specimens and of choosing from amongst them the sections which show an interesting orientation.

Similarly, the method of thin films allows of identification being made of the phases which come into play in evolution to the solid state. For example, a titanium alloy with 15% vanadium and 2·5% aluminium (T-V15A), was brought into the homogeneous beta phase by treatment at 845°C. and this beta phase quenched at room temperature. Reheating for 24 hours at 540°C. produced decomposition of the beta phase into fine platelets orientated in relation to the matrix, and the microdiffraction pattern shows that this is phase alpha.

Copper-2% beryllium alloy

Similarly to the aluminium-copper alloys, copper-beryllium alloys are susceptible to structural hardening by precipitation of a sub-microscopic phase, which is described as γ', the equilibrium phase being γ. But the structure of γ' and the mode of transformation $\gamma' \rightarrow \gamma$ are very poorly known. Specimens of copper-beryllium alloy are easily thinned by means of the F2 bath (0·4A strength) and an investigation which was made has already made it possible to discover the fundamental characteristics of the evolution during reheating, the method of examination calling into service electron microbeams of the order of the micron. It has already been stated that one of the basic advantages of the thin section technique is that it allows of easy study of monocrystals forming part of a polycrystalline assembly. Diffusion techniques (that is to say, diffraction outside the Bragg angles), developed by Guinier for X-rays and of which it is not necessary to recall the importance, are thus directly transposable in diffraction of electrons without it being necessary to prepare monocrystals specially. Fig. 9 shows a diagram taken from a specimen of Cu-Be 2% at the beginning of its hardening. There can be recognized in it diffusion streaks parallel to the <100> axis of the reciprocal lattice, which recall the diffusion streaks which Guinier recorded with X-rays in his study of structural hardening of Al-Cu 4% alloys. Electron micrography allows of simultaneous recording of the precipitates, which, in the present instance, have a size of only about 100 Å. (fig. 10). The eutectoidal transformation of beta into alpha plus γ can also be followed and fig. 11 shows that alpha is developed in the form of polycrystal lamellae (which give rise to ring sections) whilst the remain-

ing β matrix is transformed into γ by simple passage from order to disorder, retaining its monocrystalline aspect (point spots forming the square lattice (001) on fig. 11).

Aluminium-magnesium alloys

The structural evolution of these alloys, during prolonged holding at temperatures of the order of 100 to 250°C., has been the subject of numerous investigations, which leave many problems in suspense. Since the work done by Lacombe, it is generally admitted that a precipitation takes place of one transitional phase, called β′, but the structure and mechanism of formation of this phase are still unknown. The equilibrium phase, β-Al_3Mg_2, itself has long been described as hexagon with parameters a = 11·38 Å.-c = 17·87 Å., whereas nowadays it is given a face-centred cubic structure with parameter a = 28 Å. Fig. 12 shows the direct micrograph of a monocrystal constituent, β in a cast Al-Mg 15% alloy, thinned with an AC2 bath, at 65 volts. There will be noticed sub-grain boundaries and many structural faults, particularly stacking faults which are shown by fringe systems. These β constituents are, moreover, flecked by very fine pinpoints, of which the diameter is only about 100 Å. The microdiffraction patterns formed by these constituents, one of which is shown in fig. 13, correspond quite well to a face-centred cubic lattice of mesh a = 28 Å. The diffraction points are very close together owing to the large cell parameter (notice, in particular, the points in the region of the centre of the lattice). In addition, small rings can be seen, these being attributable to the aluminium lattice. All these observations taken together allow of a conclusion being drawn that the very small spots on the micrograph represent microdrops of aluminium, of 100 Å. diameter, enclosed in the monocrystal β. We are therefore confronted not by the pure β phase, but by the eutectic Al-Al_3Mg_2, containing about 2·5% α phase. It is almost certain that no other actual laboratory method would have allowed of this result being recorded.

High-resolution examination of the constituents β, by the method developed by Menter, enables the reticular structure to be resolved as can be seen in fig. 14 where the reticular planes (220) are clearly seen.

If we now thin down an Al-Mg 10% alloy, quenched and reheated for one month at 120°C., we can observe lamellae of precipitated β′ phase (fig. 15) and record their microdiffraction pattern. It is confirmed that there does really exist a β′ phase different from the β phase, but these diagrams are very complex and it has not been possible to obtain, up to now, definite indications of the structure of β′. It is proposed to continue the study of high-purity Al-Mg alloys but also to examine by the same method the influence of iron in commercial alloys, and especially of silicon, the fundamental role of which has been established, in other studies, in the mechanism of intercrystalline sensitivity to corrosion.

Al-Si alloy, 1·2%

The authors have used the same method to study precipitation in Al-Si, 1·2% alloys. After quenching at 570°C. and holding for 2 hours at the ambient temperature, the vacancies precipitate and form dislocation bands of approx. dia. 250 Å. (fig. 16). After ageing for 3 min. at 350°C., on the other hand, the silicon precipitates in very fine particles (fig. 17).

Various constituents

In addition to the main elements, various other elements in small proportions are generally added to alloys. These other elements give birth to constituents of which the structural analysis is difficult owing to their small volumetric importance. They can, however, be isolated and analysed with comparative ease by the thin section method. For instance, in Cu-Be 2% alloys a few tenths of 1% of nickel are added.

Monocrystals, less than 1μ in size, give a microdiffraction pattern which can be perfectly identified as being that of a regular cubic phase of the Cs Cl type, with parameter 2·60 Å. It is indeed of the Be-Ni phase, probably containing copper in solution, from which it may be concluded that nickel fixes part of the beryllium.

In the same field of ideas the importance of small additions of chrome and manganese in light alloys is well known. The problem of identifying the constituents to which these elements give birth is an extremely complex one and, up to now, there is no measure of agreement on the subject of their structure. A systematic study of them has been undertaken. Fig. 18, for example, shows a constituent of about one-tenth of a micron in size in an Al-Mn 1% alloy, and it has been possible to identify this as Al_6Mn. On this same micrograph there will be noticed the subdivision of the grain into subgrains of about 1μ, separated by dislocation walls.

Steel, beryllium, uranium

To conclude, we give some examples to demonstrate that the method can be applied to most metals and alloys.

Fig. 19 is a micrograph of a thin film of an 0·85% carbon steel, and shows a pearlitic structure.

Beryllium is a metal of increasing importance in the nuclear and missile fields. It can be thinned

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Stress-relieving aluminium

Cooling to sub-zero temperatures and reheating rapidly can introduce residual stresses opposite to those produced by conventional quenching. This is the basis of a new method of stress-relieving aluminium parts of irregular shape which was described in 'Metal Progress,' August, 1959, by H. N. Hill, R. S. Barker and L. A. Willey of Alcoa Research Laboratories, Aluminium Co. of America, New Kensington, Pa., U.S.A.

A NEW WAY TO RELIEVE the residual stresses in quenched aluminium parts has been devised: Quenched parts are cooled to –320°F. in liquid nitrogen and then heated rapidly in a blast of steam. Since this technique is essentially the reverse of quenching (the parts are rapidly heated, rather than cooled, through an extensive temperature range), stresses induced by previous quenching are reversed and largely cancelled out. Already effective with some forgings, this treatment is expected to be useful for stress-relieving irregularly shaped parts that cannot be handled by other methods.

Problems in conventional stress-relieving

Many commercial aluminium alloys attain their strength through heat treatment. While the specific treatment depends on the alloy, the part is usually quenched in water from about 500°C. Stresses occur because the surface cools faster than the centre, and temperature gradients spread throughout the part. When the bath temperature is finally reached, these gradients vanish, but on disappearing they set up a system of residual stresses. Usually, the surface is in compression and the centre is in tension. Stress magnitudes vary with alloy and severity of quench. Solution treatment is generally followed by precipitation hardening or ageing at 120–230°C. This treatment further enhances the strength but has no significant effect on the residual stresses.

For many applications the stresses resulting from heat treatment are harmless. However, when a heat-treated part is machined, removal of metal disturbs the original stress balance and a new balanced system must be set up. When this happens the part usually warps. Since this can be a serious problem, material with a low level of residual stress must be supplied if it is to be machined later.

Residual stresses can be relieved by heating or by mechanical deformation. However, heating is not practical for heat-treated alloys because temperatures high enough to relieve stresses lower the strength. Parts not suited to stretching, such as hand forgings and some die forgings, can be compressed. Stretching and compressing have some minor effects on mechanical properties. In irregularly-shaped parts where these methods are impractical, there was need for a method of relieving residual quenching stresses, preferably one that would have no detrimental effect on mechanical properties.

Principle of 'uphill quenching'

It was reasoned that, since residual quenching stresses result from thermal gradients introduced when the part is being cooled, it should be possible to produce opposing residual stresses by heating a cold piece rapidly. In other words, an 'uphill quench' was needed. Residual stresses thus developed should counteract and cancel the quenching stresses. To be effective, such a 'quench' would have to produce temperature gradients large enough to cause local plastic deformations. Furthermore, temperatures should not be high enough to affect properties. These requirements suggest cooling to a sub-zero temperature and reheating rapidly.

The method developed involves an 'uphill quench' of such severity and applied under such conditions as to result in considerable reduction in residual stresses, with no effect on mechanical properties. It has been labelled 'thermomechanical' to connote that, while the treatment is thermal, the relief of residual stresses comes through mechanical plastic deformation.

The procedure is as follows:

1. After quenching, and before appreciable precipitation hardening has occurred, cool the part to a very low temperature.

2. Remove part from the cooling medium and immediately blast all surfaces with steam at high velocity.

3. Age the part as prescribed for the specific alloy.

This treatment has lowered the level of residual stress in aluminium parts more than 80% without changing properties significantly.

Experimental work

Samples of 2014 and 7075 aluminium alloy plate were quenched from the solution heat treatment temperature, cooled to sub-zero temperatures and

rapidly reheated. Best results occurred when the specimens were blasted with steam directly from the −320°F. of liquid nitrogen. Residual stresses were determined by measuring the changes in length and curvature which occurred when the alloy plate samples were sectioned.

Cooling to 000°C. followed by rapid reheating with steam resulted in a reduction in stress level of about 50%. Greater reductions were obtained with lower temperatures. The maximum temperature difference between surface and centre increases as the cooling temperature is lowered.

Boiling water immersions or hot water jets were not adequate for 'uphill quenching.' Only the steam blast reduced residual stress to the desired degree. Two features of the steam blast help to attain the required high heating rate—the heat of condensation of the steam, and the blast which removes the condensate from the surface of the part being treated.

The effectiveness of the steam blast was influenced by the temperature to which the part was cooled. The reduction in residual stress was greater when the 2014 samples were cooled to −320°F. than when cooled to −100°F. When reheated by immersion in boiling water, however, the maximum temperature difference between surface and centre and the reduction in residual stress range were the same, whether the sample was cooled to −320 or to −100°F. In either instance the reduction in stress range was only about 20%.

Yield strength

For the 'uphill quench' to be effective the thermal gradient must be great enough to produce local plastic deformation in the part. Thus, for a given thermal gradient, the effectiveness will depend on the yield strength of the material. For this reason the thermomechanical treatment must be applied before the yield strength has been raised by ageing. The treatment is ineffective if applied to a part in the T6 temper. Tests also showed that residual stresses could be induced in annealed material (in other words, material without residual stresses) by 'uphill quenching.'

It is evident that the thermomechanical treatment cannot be applied indiscriminately. It is intended only for those parts having appreciable residual stresses introduced by quenching.

Recycling was ineffective; the same degree of stress-relief could be obtained with one 'uphill quench' as with five. Specimen thickness affected stress-relief in that the thicker material was relieved to a greater degree. Tensile tests showed that 'uphill quenching' did not alter the mechanical properties significantly.

Application to die forging

Though the laboratory work on plate samples had proved that the method would work, it remained to be demonstrated on a commercial part. Therefore, a 7075 alloy die forging was chosen on which stresses had been successfully reduced by compression.

Although relief varied at different sections, stresses were reduced considerably in all regions where they were high. When these results were compared to those obtained on an identical die forging which had been relieved by compression, stresses were found to be at the same low level.

On the basis of this success, further work is being done to develop the treatment as a commercial procedure.

Application of electron microscopy

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and its structure studied by the same method. Fig. 20 shows a micrograph of a thin film of rolled beryllium in which the sub-grain boundaries and the dislocation networks in the sub-grains can be seen.

At the other end of the atomic scale it is equally possible to thin uranium with the A.5 bath at 45 volts as has already been published by the authors.

Future developments

The reader will be familiar with the developments of the direct examination of thin films with the electron microscope, obtained by Bollman, Hirsch, Whelan, and their collaborators in the field of metal physics, and by Nutting, Thomas and their collaborators in the field of the structural development of light alloys. The authors hope that the simple and rapid method of preparing thin films described here will enable new developments to take place in these studies and also make possible an extension of the method to control examinations in industrial laboratories.

APPOINTMENTS

Mr. D. N. Steeley has been appointed sales manager of Standard Industrial Motors at the G.E.C. Engineering Works, Birmingham. Mr. Steeley was educated at Repton and joined the General Electric Co. Ltd. as a student apprentice in 1949. He completed his national service with the Royal Navy in 1956 and reached the rank of lieutenant. On his return to the company he was appointed an assistant branch engineer in London.

Mr. G. Marchant has been appointed general manager of the Wolverhampton and Hednesford factories of the Fafnir Bearing Co. Ltd.

Spark machining symposium

Electrode materials

J. L. ADCOCK, M.I.Prod.E.

This article is the third of a series on spark machining. It forms part of the symposium held late last year at Birmingham by the NADFS in collaboration with METAL TREATMENT. *The remaining papers, together with the author's synopsis and discussion, will appear in this journal bi-monthly. Mr. Adcock, chief engineer, Wickman Ltd., surveys the range of suitable materials available for machining electrodes and considers their relative merits in respect of cutting properties and low wastage*

WHILE the pure electrical definition of 'electrode' can be applied to both tool and workpiece in the spark machining process, by common usage the term has come to be applied to the tool only. Because the actual production of electrodes is already acknowledged to be the largest single factor influencing the economics of the spark machining process, the choice of electrode material must be regarded as of equal importance and significance.

There are a great number of materials which can and have been used for electrodes, since any material which will conduct electricity can function in this capacity to some degree; however, there is a wide difference in performance between these materials. It was thought in the early days of development that one particular material would be found to show universal superiority for electrodes and from the viewpoint of its metalworking capabilities this has been confirmed. The additional considerations which have arisen as a result of the exploitation of the process as a production tool, namely availability and cost, and ease of processing, have favoured the selection from several alternatives on occasion in order to secure the most suitable for a given application.

Developments in spark machining equipment during recent years have enabled very substantial improvements to be made in the surface finish obtainable, metal removal rates, and accuracy. In addition, electrode wastage has been markedly reduced and the employment of a wider variety of electrode materials made acceptable. These developments have brought about the situation where optimum requirements for the spark machining operation itself can sometimes with advantage be subjugated to availability or cost of production in respect of the choice of electrode material.

The primary qualities sought in an electrode material are that it shall cut the workpiece quickly and suffer the least loss itself while doing so. Direct comparison of cutting speed between various materials must be based on similar electrical power input during the cutting operations. Since some materials do not give similar results throughout the range of cutting powers generally employed, it is necessary to repeat comparative tests at various powers.

Variables affecting electrode wastage

In examining electrode wastage we are concerned with the ratio on a percentage by volume basis of material removed from the electrode compared with that removed from the workpiece, and affected by other variables than electrode material. The most important of these are:—

(1) *Rate of cutting.* Generally the wastage ratio increases with cutting rate.

(2) *Cross-sectional area of electrode.* Wastage ratio is reduced with increase of cross-sectional area.

(3) *Workpiece material.* Sintered hardmetals induce considerably higher wastage ratio, and high alloy steels containing vanadium or molybdenum a somewhat higher ratio than more normal steels and Nimonic alloys.

(4) *Configuration of electrode.* A form having slender projections or narrow sections will exhibit a higher wastage ratio than one of comparable cross-section which is more compact. Thus a star section will show more wastage than a circular section.

(5) *Depth.* Deep cavities or long through forms will provide a higher electrode wastage ratio than shallow ones. The reason being the increased difficulty of debris removal and proper coverage of the operating zone with di-electric liquid, two

factors which interfere with the correct spark machining function.

In our opinion the best material with regard to low wastage and fast cutting is a sintered composition of tungsten and copper which provides this performance over a wide range of cutting powers. This material is also equally effective on all the normal workpiece materials including sintered carbides. Its more widespread use is hindered on account of its high price and the fact that it is only available in elementary forms such as round, square and rectangular section, of limited length. The appropriate grades of the material are, however, readily machinable by orthodox metal-cutting methods and economy in its use can be achieved by brazing just sufficient length to provide the operative portion of the electrode to a shank of brass or steel. Use of this material is particularly attractive for the spark machining of intricate cavities such as coining or embossing dies where the sharpest possible impression is required. As production of such an electrode may involve intricate machining or expensive skilled engraving, the comparative cost of the electrode material is small; especially when employed in the form of a tip affixed to a shank of cheaper material.

From here onwards compromise enters into the question of material selection even from the standpoint of cutting performance alone, so we will endeavour to include in the following appraisal of the commonly used materials, the attendant properties which need to be considered along with each one in making the choice of material for a particular set of circumstances.

Copper

We would rate copper as the most important of these materials from a general selection point of view. It shows low wastage on all cutting power ranges, provides very good stock removal on coarser ranges, but does not retain the latter property very well on the fine ranges where brass can frequently show superiority in the matter of stock removal. Copper is not sensitive to change of workpiece material and performs well on a wide variety of steel, Nimonic alloys or carbides. The best results are provided by copper in the annealed state. Small additions of other metals, such as arsenic in commercial sheet or tellurium in the free machining grade do not materially affect its performance. The somewhat higher content of beryllium which is added to give spring properties after heat treatment has been found to detract very considerably from its properties as a spark machining electrode. A 3–4% addition of cadmium has been claimed to provide an outstandingly good electrode, but our own experience does not substantiate this, for we have found this alloy to be inferior to commercial copper both on stock removal and wastage ratio.

Electro-deposited copper, particularly if produced from a fluoborate bath with periodic current reversal, provides a purity and grain structure which are excellent for our purpose. Material thus obtained is relatively expensive, however, and economic use of this method is confined to small and intricate forms. A less expensive form of deposited copper which is effective as an electrode is obtained by metal spraying, though the porous nature of the deposit detracts from its physical strength so that use of this method should be confined to electrodes of robust configuration or the use of modest power during the spark machining operation; otherwise there is a danger of pieces of electrode material breaking away and spoiling the required impression.

The merits of copper are not offset by unduly high cost, and by selection of the appropriate grade and knowledge of the correct technique it is amenable to all forms of manipulation including casting where this does not involve abrupt changes of section or much detail. The variety of standard shapes and sections available contribute to reduce costs where machining operations are involved.

Brass

Brass is considered to follow copper in order of importance as a general material and, indeed, up to the last few years it was almost universally used as an electrode because of its steady cutting properties on a wide range of applied power and over the widest possible variety of workpiece materials. It does, however, suffer from a steeply increasing wastage ratio as the cutting power is increased, which has become an increasing drawback as generators have developed to provide increased stock removal rates. As previously indicated it can frequently surpass the stock removal rate of copper on low power settings and under these conditions its wastage ratio is very little inferior to copper. It is therefore often a first choice as a finishing electrode and its use on faster cutting rates is justified where wastage ratio is not an important consideration. As in the case of copper, some improvement in wastage ratio can be gained by annealing.

Although the name brass is given to a wide range of copper and zinc alloys, the main commercial grades fall into the 70.30 and the 60.40 copper to zinc percentage compositions. There is very little to choose in the matter of performance as an electrode between these two grades, and the 60.40 grade in addition to being cheaper than the higher copper content alloy, has a much greater commercial usage and is therefore more readily available. In the form of sheet and strip it is known as ' common brass ' and it also forms the basis for sand and die castings and hot forgings. With the addition of 0·5 to 3·5% lead whereby free cutting and extru-

sion properties are improved, it still provides a satisfactory electrode material which is commercially available in a great variety of sizes and standard sections at moderate cost.

Tungsten

Tungsten must be considered as a material of some merit since it provides an extremely low wastage ratio over a wide range of applied cutting powers. Its stock removal rate is low, however, and it has the further disadvantage of high cost and the fact that its mechanical manipulation is confined to grinding on account of its hardness. In spite of these drawbacks it has its small sphere of usefulness as an electrode for apertures of small area, especially where they are comparatively deep. These two conditions are conducive to high electrode wastage which can frequently be reduced to an acceptable level by the use of tungsten. Its inherent stiffness is a useful quality in long and slender electrodes which are often required for this type of operation. The use of tungsten is limited to small areas by cost and its low stock removal rate, and is, of course, also confined to near elementary shapes where little or no electrode machining is required. Tungsten should therefore be classed as a specialized electrode material. The foregoing remarks apply equally to tungsten carbide and selection between the two should be made on the basis of cost and availability.

Copper-graphite

Mention should be made of copper-graphite mixtures as electrode materials, since they show good stock removal rates and a low wastage ratio. Their poor mechanical properties are a hindrance to their wider use, for they are not only likely to shed portions of their form, if it is of a delicate nature, during the spark machining operation but also, extra care must be exercised in the holding means employed to provide good electrical contact and yet at the same time to avoid distortion or fracture of the electrode shank. To utilize available elementary shapes of this material and produce electrodes by conventional machining is a messy undertaking frequently accompanied by frustration when a portion of a partly completed electrode breaks away under machining stress. The potential attraction of the material exists where repetitive operations warrant the provision of dies to produce copper graphite electrodes economically from the pre-sintered mixture.

Our own experience in the use of this material indicates that approximately 65% copper and 35% graphite yields the best results reckoned on performance only. Increase of copper content to 84% provides a material which has the added attraction of being able to be reformed to a limited extent after initial use and yet at the same time give a good cutting performance.

Improvement in the mechanical properties of this material without detriment to the spark machining qualities has been claimed for the addition of 10% cement to the mixture of copper and graphite. The three constituents must be very thoroughly dry mixed to ensure even distribution and then brought to a paste-like consistency by the addition of water. The mould having been filled with this paste is subjected to a pressure of 6–10 ton/sq. in. to form a damp compact. The hardening of the cement bond takes the place of a subsequent sintering operation where this constituent is omitted.

Copper graphite can therefore be rated as worthy of consideration for continuously repetitive operations where the form and size is such as to provide an electrode which is not fragile.

Cast iron

Certain grades of cast iron have been found to provide an extremely low wastage ratio, but generally accompanied by poor stock removal rates. An exception to this occurred in our experience with one grade of Meehanite produced by one particular foundry, which gave good removal rate as well as low wastage particularly on the lower power settings. The same results were not obtained from an allegedly similar product from other foundries and neither chemical analysis nor foundry technique could account for the difference in performance. Cast irons generally, even if ordered to specification, we have found to give such a variability in performance as to lead us to only recommend this material where a supply of suitable castings to the required form is available.

Aluminium

In our view the foregoing enumerates the materials which have some degree of inherent merit as spark machining electrodes when reckoned on performance alone, but as previously indicated, it is expedient to consider some other materials which have an appeal to certain groups of trades by virtue of availability, or lend themselves to the extension of existing trade practice to include the additional use of spark machining. In this category appears aluminium, the use of which is naturally attractive to the trades concerned with its extrusion and casting on the score of ready availability at a low price. In the case of repeat or replacement dies the form required for the electrode is already in existence as a product in the two sections of the aluminium industry mentioned. Easy machining and the facility of chemical reduction by a caustic soda solution have also contributed to the increasing use of aluminium as an electrode material by the

sections of industry concerned with its manipulation. Its use provides high stock removal coupled with a fairly high wastage ratio on the coarser settings but on finer cutting ranges its performance is poor on both counts. It is not worthy of consideration for use with tungsten carbide workpieces as this combination provides a very high wastage ratio. Selection of electrode material from the considerable number of aluminium alloys is not critical in determining performance and since the use of this material is in nearly every case the result of attendant circumstances the particular alloy available will be used.

Steel

Steel may be used as an electrode both on ferrous and carbide workpieces; on high cutting powers its performance is very poor both on cutting speed and wastage ratio. On finer cutting ranges its wastage ratio is considerably reduced and approximates to that of brass while its stock removal rate is about half that of brass.

For a finishing electrode which should be called upon to remove the minimum amount of material, this is not nearly such a serious drawback as it sounds. This slow removal rate is also accompanied by a better surface finish on the workpiece than would be given by a faster cutting electrode material, so that if we add the facts that it is easier to machine steel to close limits of accuracy than the alternative non-ferrous materials, and it can be held on magnetic devices for grinding, we must conclude that it has its place as a finishing electrode on accurate operations of comparatively small area. In producing press tool dies by spark machining the steel punch can frequently be made to include sufficient length to be used as the finishing electrode for the die. This used end is then cut off, leaving the punch complete and unmarked.

Zinc-base die castings

With the improvements which have taken place in zinc-base die castings in recent years, allied to the more tolerant nature that spark machining equipments have developed towards electrode materials over a similar period, this material must be considered as a useful addition to the range. Its potential application divides into two main fields, the first of which is the use of available production die castings—which no longer consist of a metallic sponge surrounded by a skin of indeterminate thickness—to provide electrodes to produce further similar cavities; while the second is the use of the basic material as an easy casting medium.

Interest in the first category is naturally confined to die-casting manufacturers and contract mould makers who work for them. The second method of usage, however, which envisages the material as an offhand casting medium is of interest to a much wider variety of trades. In the first place the production of electrodes to repeat existing forms can be undertaken by using available steel dies or moulds and secondly casting moulds can be prepared of self-setting stone-like material such as plaster of paris or titanite. Even where a pattern of the requested component does not exist, the preparation of such a mould can be made by a combination of machining and hand methods in much less time than a comparable steel mould, particularly if the operation is undertaken before the mould material has set completely hard.

The cutting performance of this material is very much inferior to brass or copper on all cutting ranges, but within these limitations it shows up best on higher cutting powers, where the wastage ratio can be expected to be about double that of copper coupled with a stock removal rate of two-thirds that of copper. On lesser cutting powers its relative performance degenerates to about three times the wastage ratio of copper with a stock removal rate of approximately half.

AUTHOR'S SYNOPSIS

Mr. J. L. Adcock (Chief Engineer, Wickman Ltd.), delivering the synopsis of his paper, said that he had attempted to offer some advice on the range of materials which were at present suitable for machining electrodes because he believed that the problems of electrode manufacture had retarded a wider adoption of the process in some industries.

The process was relatively new, particularly to the forging industry. It was a complete break-away from other metal working processes, and naturally had its problems. Economic benefits were undoubtedly available for those interested enough to 'have a go.' The machine tool industry had provided a variety of spark-machining equipments which could be applied to a very wide variety of industries and to an even wider range of metal working applications, many bearing little or no technical similarity to any other.

Most users had adopted spark machining for a special purpose or for the solution of a particular metal-working problem. With the assistance of published information and equipment manufacturers, they had solved to a large extent their own production problems and now reaped the benefit. The rewards which the process offered to the forging industry were more substantial than those offered to any other industry. Mr. Cooper's* contribution to the symposium had been ample proof of that, but the industry must be prepared to help itself. To use a popular and somewhat abused

*'Spark erosion for industry', E. Cooper, British Motor Corporation Ltd., will be published in METAL TREATMENT later this year.

phrase, industry must adopt a little ' do-it-yourself ' in this technique, with the knowledge that for this process standard cutting tools applicable to a variety of jobs could not be ordered. Whilst the machine tool industry could help to a large extent by discussions and advice, Mr. Adcock could not conceive an electrode manufacturing service ever being an economic possibility.

DISCUSSION

Mr. C. Burgess (Guest Keen & Nettlefolds (Midlands) Ltd.) said that he felt hardly qualified to discuss this subject, as he had had very little experience with spark machining. His experience was limited to a few cold form heading dies, which constituted cheese-head or hexagon at a shallow depth. He had always used copper. Would Mr. Adcock confirm that copper was best for his purpose? He had heard also that, at a cost, the electrode could have a chrome surface. The tools with which he had had experience had been for special purposes only. His problem at the time had been finding the capacity to make electrodes. He had not the use of the machine at present, although he might get it back later. He had attended with the object of gaining information.

Mr. Adcock, replying, agreed that from that very brief description copper was the best method Mr. Burgess could use. A little gain might be experienced by using brass for the finishing electrode, but for a comparatively straightforward job it would be better to complete the operation with copper all the way through.

Mr. Adcock said that his experience with chroming the surface of the electrode had not been happy. It had been tried many years ago, and it had been hoped that it might have proved worth while. It was not a practical dodge or manoeuvre in which to engage. He would be interested to hear if anyone had any results which would either substantiate or confirm that.

Electrode-making capacity was a problem facing many firms. Method was also a problem. A combined effort must be made to tackle the problem. The only way in which it could be surmounted was by everyone sharing information and experience.

Mr. H. A. Whiteley (Vaughan Bros. (Drop Forgings) Ltd.) said that, as a mere drop forger, he was in some trepidation about rising at such a meeting. Drop forgers' thoughts throughout were that a No. 5 die steel or ordinary carbon dies were the limit to which they were going. That was entirely wrong, because with a new process such as spark machining thoughts should be turning to better die steels than the No. 5, which had been the only steel used in any quantity since about 1924. He was sorry to inform the visitors of that, but some of his friends had told him how behindhand the drop forging industry was, and how with spark machining it would be possible in future to work to plus or minus $\frac{1}{4}$ in.

Mr. Adcock had spoken of the high price of tungsten copper sintered material, but had not said how high it was. Would Mr. Adcock tell the delegates in confidence, so that they could return and decide whether after all they would file it out of brass? The metallurgical field as applied to drop forging seemed to be due for considerable widening. Metallurgists had to know all about the various electrode materials, coupled with the possibility that there would be new steels containing something more than carbon and nickel.

Mr. Whiteley said that, before returning to the drop forging industry, he had had a fair amount of experience in casting. He had cast many small class 1 castings from patterns which were light-alloy drop forgings. What were the characteristics of cast materials for electrodes? Many delegates did not have the wonderful long runs of material to enable them to know. Their dies had to be one-offs or two-offs. His thoughts turned to his own possibilities of casting in brass or copper alloys patterns which would require the minimum of scraping or machining to make them into electrodes. Copper was stated to be quite a good material for electrodes. Had anybody tried casting the electrodes? What was the effect of phosphor copper or the remaining small percentage of phosphorus which was left in copper when it was cast?

He agreed wholeheartedly with Mr. Adcock that it should be printed in large letters throughout the drop forging industry that, if the drop forgers wanted any advance, the industry must set out to help itself.

Mr. Adcock said that it would be better for him to keep out of such domestic issues as better die steels. He supported Dr. Rudorff's point that as die steels improved so the economics would turn towards spark machining. It was something that the industry as a whole possibly would do well to consider, because the best could not be obtained from spark machining the day after it was adopted. Although there was much more knowledge available, it took at least a month to get down to a particular field of technique and even then one could look forward to improving methods of production.

Mr. Adcock said that he had left the price of sintered copper tungsten comparative to the other materials because, bearing in mind that he was speaking primarily to the drop forging industry, which in the main was concerned with comparatively large pieces of material, he had felt that copper tungsten would be quite prohibitive as a general material. There would be delegates present with much more recent and accurate figures available, but he recalled that a $\frac{1}{2}$-in. dia. stick of the

material, 7 in. long, was about £4 15*s*. It was obtainable only in very elementary shapes, which was another barrier to which he had drawn attention in his paper.

A delegate stated that the material cost £2 8*s*. for an 8-in. stick of ½-in. dia.

Mr. Adcock stated that this meant that the industry was starting to use it and it was becoming cheaper.

As regards spark machining, there was nothing against cast materials for electrodes. The usual barrier to their wider use was their accuracy and the fact that their skin was usually fairly poor. For a large roughing operation they were well worth considering, even if all sorts of knife and fork methods were adopted to produce a cheap one-off sand mould. They certainly reduced the amount of hand work to provide a satisfactory electrode. Generally it was necessary to operate with more than one electrode, so they must be consistent in size. In other words, they were perfectly satisfactory if they could be made well enough.

As regards phosphorus in copper castings, Mr. Adcock said that his firm had used cast copper electrodes on a number of occasions and any deleterious effect was not sufficient to be noticed.

Mr. R. A. Riley (Alfred Herbert Ltd.) asked if certain electrodes were more suitable for certain materials being machined, particularly in respect to tungsten carbide.

Mr. Adcock said that they were. Completely to enumerate the effects was an involved procedure, but most users of the process would agree that it was best to generalize in the effects on these pairs of materials. Occasionally one came across a completely incompatible pair where the erosive effects were reversed. He knew of only two of those. When the user came across the first such case, he was driven into a ' flap,' but having found that case he was looking out for such cases in future. There were very few cases. It was also possible to use similar materials for each of the pairs, which could very well be surprising. The only substances which were barred for tungsten carbide, from a purely usage point of view, were aluminium because it wasted so quickly and die cast metals for a similar reason. All materials containing nickel were extremely poor for electrodes.

Mr. Riley asked if there were any special electrodes for tungsten carbide.

Mr. Adcock said that there were not. Sintered copper tungsten was undoubtedly the best material for tungsten carbide, but that was brought out in the paper as being general.

Mr. T. Burnett (Firth-Derihon Stampings Ltd.) said that during Mr. Farley's lecture the question of electrode designing where uneven wastage occurred had been raised. If a number of electrodes were used instead of one specially designed to take care of uneven wastage, obviously they would be better off. From Mr. Adcock's synopsis it appeared that in order to obtain optimum results the electrode should be of different materials. Did Mr. Adcock think that the advantages of using the various materials compensated for the added expense of buying specific materials? Further, if the cavity to be sunk into the die could be divided into standard shapes would it be possible to use a composite electrode? If so, what were the advantages and disadvantages?

Mr. Adcock, dealing with uneven wastage, said that he thought that Mr. Burnett was driving at an allowance to compensate for that. A hemispherical electrode had been mentioned during a previous discussion. That was a type of thing for which it would be very easy to compensate. He had stated that electrode wastages varied in different types of operations. Therefore, the procedure with that compensation would be to try one uncompensated electrode, determine the ratio of wastage on a particular machine and finish on which the job was to be used, lay out on squared paper an enlarged section and add the proportionate amount in the form of a sphere. A compensated form for the piece would then be arrived at. Obviously that was worth while only if many operations had to be carried out. This was habitually done in arriving at corrected shapes. It frequently reduced the number of electrodes considerably, and on a particular contouring job enabled the required shape to be arrived at absolutely. To warrant this procedure, it must be a highly repetitive operation.

Mr. Burnett's next point had been different materials on the same job, in other words the distinction between a roughing and a finishing electrode. If there was some advantage to be gained, as there was, and both materials were available and had to be made, it was no more difficult to make one out of another material. The deciding factors were what was available and how they were put out in the shop for manufacture. From the purely spark machining viewpoint there was some advantage to be gained. In the section on steel finishing electrodes Mr. Adcock had pointed out that the aim of the intelligent operator should be to allow as little material as possible for the finishing electrode, which diminished any value that the electrode might have *per se* as a finishing tool. That diminished also the need to change from one material to another.

The use of the elemental electrode built up from standard sections was quite possible and highly practical. There might well be an extension of that system, particularly on the larger and larger forms.

Supplementing this answer, Mr. Adcock said that it was possible to assemble everything into a

composite electrode and do it in one operation. It added a little more to the tool making, but reduced the machining slightly. The internal conditions dictated which was cheaper. From the spark machining angle it was quite effective. Further, where there were incremental accurate movements built into a spark machine, a complex form could be produced by simply using elemental shapes and doing it sequentially. With the increase in cutting speeds, that became more and more possible. Indeed, it was now a probable way of going about these jobs. It came down to the eternal question that some good production engineers were needed on the process.

Mr. O. Collins (Bloxwich Lock & Stamping Co.) asked for a ratio for the cutting speeds for the well-known electrode materials used, taking copper as 1·0, and also a ratio for surface finish, taking everything else as equal.

Mr. Adcock said that it was not possible to do that off the cuff. He could prepare a paper which would go some way towards dealing with it exhaustively, but it was a huge subject. He had pointed out all the variables. He might be able to deal with a specific instance of the difference if it was in the form of a single question.

Mr. O. Collins then asked for the ratio between copper and one other electrode material, for both removal rate and finish.

Mr. Adcock, dealing with removal rates, said that much had been heard, and rightly so, about flushing, which was quite a problem. It was a problem which became more acute on the finer cutting ranges. Therefore, those would vary from range to range. Taking a generalized picture, it was possible to say that copper tungsten would probably be 1·2, taking copper as 1·0. Brass would be about 0·8. Aluminium could be as high as 1·0 on cutting, but would be about twice as high on wastage.

Mr. Adcock stressed that this was not a very straightforward question to answer. Without taking a specific condition and material, he would rather not go into it any more deeply.

Mr. R. Robinson (Clydesdale Stamping Co. Ltd.) said that his company was at present producing electrodes by cold pressing. The finished product was left in the cold work state. He asked whether that condition would have any serious effect upon the ultimate cutting properties of the finished electrode.

Mr. Adcock said it would have no serious effect. He estimated the gain obtainable by annealing at about 5% or less, mainly where there were projections of small area. The gain stemmed from the fact that the annealed material was somewhat more ductile, and so the wear due to attrition was somewhat minimized. It was, in effect, the old condition of the rifle bullet and the blanket. Unless it was a very small area sharp-projection type of material it would not be worth while adding a further annealing process, with the ever-present trouble of introducing distortion in the cooling or during or after annealing.

Mr. W. J. Overton (Northern Aluminium Company Ltd.) asked if it was a practical proposition to use a forging from a forging die as a future electrode for re-sinking the die.

Mr. Adcock said that in principle it was. In practice it was largely bound up with the shape of the impression, in other words if there was a big difference between maximum and minimum diameters. With a connecting rod there was a big ratio between length and width. For the spark machining process there was a constant annulus. In other words, a sum was being added all the way round to the electrode on the size of the impression, whereas with the die there was a variable shrinking allowance which was proportionate to that length/width ratio. On a component of that sort of shape there would be a deviation by that shrinkage amount. If the tolerances allowed the variation to be accepted, that was the way to do it. There would be cases where the tolerances would not allow it.

Mr. G. Elvins (Garringtons Ltd.), stating the hypothesis that increased cutting rates were a desirable feature for selling equipment and buying equipment, asked whether the present problems relating to materials for electrodes and the manufacture of electrodes were likely to restrict an increase in cutting rates in the future.

Mr. Adcock said that he did not think that there should be any restriction on cutting rates due to electrode materials. He saw no reason why the rate should not increase. It had been already brought out that metal removal was proportionate to an area. Therefore, the loading or duty on the electrode was very little different. From a particular point it was not being asked to do any more work. Mr. Adcock could see no logical limitation on materials.

Mr. Elvins added that at present there was a problem in many equipments with regard to electrode wear which was related to cutting speeds. Was any increase in cutting speeds, which had a commercial value, likely to increase the problems with regard to electrode materials and manufacture?

Mr. Adcock agreed that if faster cutting rates were achieved more electrodes would be needed to do a similar job. The duty of manufacturers now was to concentrate their efforts, not on increasing rates, but on improving the ratio of surface finish at a given rate. When they could look forward to reducing electrode wastage, they could look forward to an almost constant annulus between roughing and finishing, but they might have to pay the penalty of

the operation taking a little longer. His view was that more than that would be recovered by saving the user from providing so many electrodes and making such a large allowance on his electrode size. The question raised by a previous delegate would then be more possible.

Mr. D. Vale (Impregnated Diamond Products Ltd.) said that most of the queries he had wished to raise had been adequately answered in the very comprehensive discussion which had taken place. He wished to state that increased electrode wear with high stock removal rates had definitely not proved to be the case with the rotary impulse generator. He therefore felt that the point about needing more electrodes to produce a given cavity was far from the truth.

Further, Mr. Adcock had mentioned that the zinc base alloys proved more effective on a heavier cut than on a finer cut. In his experience this was far from the case. On a finer cut they were, to all intents and purposes, equal to brass. It was only on a heavier capacity that any serious electrode wear was experienced.

Mr. Adcock, replying to the first point, said that with due respect to a magnificent achievement when it was taken off the impulse generator, only half the job had been done. When the die was finished some electrodes were wasted. The basis of his previous remarks was that at present it was getting it from that stage to an acceptable stage for the forging die which was taking the time.

Mr. Adcock pointed out that he and Mr. Vale might be at variance on the zinc base castings, because he did not know with what sort of generator Mr. Vale had used those.

Mr. Vale said that he had used them with a relaxation circuit.

Mr. Adcock said that speaking on roughing his had not been with a relaxation circuit. With the time circuits the improvements to be gained on heavy impulses were very considerable.

Mr. A. J. Lawrance (Kimber-Allen Ltd.) said that, while agreeing with many of the observations made by Mr. Adcock in his very detailed review of electrode materials, he found that his experience differed from Mr. Adcock's in a number of respects. A possible explanation for that might be that Mr. Adcock's data applied particularly to one make of machine and that variations in the circuits of machines gave differing qualities to the materials used for the electrodes. Mr. Lawrance's experience was limited to the use of the relaxation circuit Sparcatron machines and was briefly as follows:—

For machining steels he rated brass the most generally useful electrode material, having a reasonably low wastage rate on all powers and being so readily available, inexpensive and easily machined or formed to shape. His firm used very little copper as, whenever it had been tried, the results had been disappointing relative to brass. Cast Mazak electrodes had been used with success and while it was difficult to obtain an exact comparison unless the same job was repeated under identical conditions but using brass electrodes, his firm considered that it had a slightly better wear resistance at about the same cutting rate as brass.

His firm had had no success when using steel electrodes for machining steel dies, finding great difficulty in stabilizing the spark, but exceptionally good results had been obtained over its limited experience of finishing tungsten carbide dies using high-speed steel or high-carbon high-chrome alloy tool steel electrodes. During a recent experiment, apertures were finish-machined on low power with each of these steels and also with copper and brass with the following comparative results. Taking brass as 100%, both electrode wastage and machining time of the other materials was found to be: copper 60%, high-speed steel 45% and high-carbon high-chrome steel 45%.

More recently his firm had used a copper-tungsten sintered material, Elkonite 10W3. He agreed with Mr. Adcock that, although expensive, this material exhibited exceptionally good spark erosion characteristics, including a wear rate only about one-twelfth that of brass, which made it an economical proposition, especially for machining intricate forms and deep cavities in tungsten carbide.

Mr. Adcock said that he did not think that there were any wide points of variance between his observations and those of Mr. Lawrance's. Mr. Lawrance's suggested reason for the difference could very well be true. In the preface to his paper he had stated that brass was at one time the universal material, certainly in the United Kingdom. As time had passed equipments had become less and less choosy on material. Speed and wastage were related to the percentage of effective time when discharges were being employed. They had heard at some length about the electrical and theoretical maximum repetitive frequencies. The practical problem was to ascertain how many of those could be harnessed to useful work. The percentage used on useful work varied from job to job and very largely with material to material, hence the different readings.

Further, it was conceivable that he and Mr. Lawrance were not talking about exactly the same power range. He had pointed out inversions in the characteristics in the ranges. He had tried to cover them. He assessed them as a normal operating range. It was possible that he was not right and that Mr. Lawrance was working at a different range, thus accounting for some differences.

Mr. Adcock said that he had not followed what

Mr. Lawrance had said about steel electrodes. He had thought at first that Mr. Lawrance had said that he could not use steel, but he then had gone on to say that he had used it.

Mr. Lawrance said that he had detailed the results of using high-speed steel on tungsten carbide, which had met with some success.

Mr. Adcock said that he agreed entirely with Mr. Lawrance's remarks about sintered copper tungsten.

Mr. R. Ing (Mallory Metallurgical Productions Ltd.) asked Mr. Adcock if he had any experience of blanking or precision tooling 0·005 in. thick material of an abrasive nature where a punch was required to slide fit in the die. Had Mr. Adcock employed steel at any stage so that the final punch could be used for putting straight in the spark eroded die, the problem being what to do to remove the gap?

Mr. Adcock said that as soon as one embarked on the word 'precision' there was a possibility of being at variance, because it was a very flexible word. His company had had experience of that procedure. If an annulus between punch and die of the order of seven-tenths of a thou was satisfactory, it could be done. By special means it could be brought closer than that. He added that his colleague Mr. Rhodes would be able to deal with the subject in greater detail if Mr. Ing wished to pursue it. In principle, the answer was that it could be done. This was in a carbide die, in other words it was an abrasive material.

Mr. Ing asked if it was possible with carbide or steel.

Mr. Adcock replied that it was if that order of clearance as a minimum was acceptable.

Mr. Ing said that a slide fit of perhaps 0·0001 to 0·0002 in., but no more than 0·0002 in. radially, was required.

Mr. Adcock said that this was getting too fine. He had no experience of getting down to 0·0002 in. annulus. He would resort to reducing the steel punch, not necessarily mechanically.

Mr. F. C. Bird (Walter Somers Ltd.) said that his first question was in relation to the press die, which had surprised him as being so successful in the past, because the commonly used composition of 60-40 brass had a duplex structure metallurgically. He would have expected it to show some differential wear which might have produced roughening at an early rate. Happily, this was not so.

As copper was expensive and melted at a reasonably high temperature, had the possibility of hollow electrodes for the larger machines been considered, even though the additional problem might arise of filling them in with a material of a sturdy but cheaper nature afterwards for centring purposes?

What were the possibilities of electrode restoration? He did not know whether the wear was twenty thou or one-sixteenth. The problem could be overcome by utilizing electrodes in succession —first as a finisher, then as an intermediate and then as a roughing tool. Was the electrode then entirely scrap? Could it conceivably be restored by cold forging, as in the case of copper? It would not be simple. It would presumably mean commencing with a flat tool at the top with a shin and at a later stage taking it out and filling in to the contour. Had this struck Mr. Adcock as cheapening the continuity of the process?

Mr. Adcock thanked Mr. Bird for raising three very good points. Differential wear on alloyed brass did not obtain. The reason was that there were at least two forces wearing electrodes. There was the spark erosion or the reverse spark erosion due to the spark take-off point. In addition, there was the attrition by bombardment from the particles coming from the workpiece. Even if the particles did not get as far as impacting on to the electrode, they exerted a very high mechanical force via the fluid round them. That might very well explain why there was not that differential of wear between the copper and the zinc.

Hollow copper electrodes were feasible and had been practised to a fair extent. If the rubber press technique could be employed, one could manage very nicely by pushing copper sheet into the die. It could not be done for every die, but was limited to shapes which would accept such a technique. It was surprising what could be done with it, however, when it could be applied.

To restore by cold forging was feasible. It was not usually possible to get rid of all the erosion marks on an electrode which had been used as a rougher. That was Mr. Adcock's experience, although Mr. Robinson, from the Clydesdale Stamping Co. Ltd., probably knew more about this. It meant that the electrode was given a useful life again, but one virgin electrode had to be popped in for the finishing operations if it was necessary to achieve anything like a fairly fine finish. Further, there was generally a fairly expensive press for this sort of electrode. Therefore, the spark machining operation had to be made secondary to availability of the press. If it could be so organized that the press was not held idle, it might very well be worthy of consideration; but to keep a large press standing by to reform electrodes for a spark machine would not offer anything very worth while.

Mr. F. J. Jones (Forgings & Presswork Ltd.) said he had been waiting to direct Mr. Adcock's attention to presses standing by to forge electrodes. There were two almost parallel channels for

making electrodes. One was the forging of them, with all its overheads and the hammer standing by and with rather terrific quantities of brass or copper being held in reserve, because the hammer was not available repeatedly. The other was the free- or press-casting of them. His company had had moderate success using free-cast electrodes on small powered machines. He asked for Mr. Adcock's opinion on the advisability of pursuing those experiments with the high-powered machines. Was a zinc alloy likely to give any better effects, remembering that it would be possible to follow with four, five or six cast electrodes much more cheaply than with one or two copper electrodes?

Mr. Adcock said that that sort of approach was thoroughly worth while. That sort of investigation should be followed up, because it could very well lead to the most economical way of making electrodes. It was absolutely impossible for an outsider, except in a completely clear-cut issue, to tell anybody what was the most economical way to make their electrodes. It so largely depended on the plant available and its loading, which might vary from time to time. Methods might have to be altered there and then. From Mr. Jones's description, it sounded a very sound and practicable approach, for which Mr. Jones's company should be commended.

required as the stack is built up. The weight of the complete charge is about 80 tons. Twelve thermocouples are placed in the charge and the throat-heating block is lifted into position. An inner cover of 17% chromium steel is then placed over the charge, a sand seal being formed at the bottom. Nitrogen gas is fed into this cover during the annealing operation. When the cover is in position, the bell furnace is lowered over it, and heating commences. With a total rating of 500 kW. heating proceeds slowly, about eight days being required to reach the final temperature of approximately 800 C. During the whole of this time the heating elements are under automatic control.

Cooling takes place under a specially designed cooling hood, which is lowered into position to replace the furnace. This hood is essentially an insulated cover with adjustable flaps at the base and at the outlets on top, which enable the rate of air flow through the hood, and therefore the rate of temperature fall, to be controlled closely. Total time for a complete annealing cycle is about 16 days and the electricity consumption is in the region of 20,000 units.

When annealed, each plate has to be flat to within $\frac{1}{16}$ in. over the whole area, otherwise the fabricated sector will not be sufficiently flat.

7,000-ton magnet core

THE 7,000-TON CORE of an electro-magnet—the biggest in the British Commonwealth and the largest in Europe outside the U.S.S.R.—is now being built at the Manor works of Joseph Sankey & Sons Ltd., Wolverhampton, for the National Institute for Research in Nuclear Science at Harwell, where it will form the largest component of a £7,000,000 7 GeV proton synchrotron, or 'atom smasher,' now under construction at the new Rutherford High Energy Laboratory.

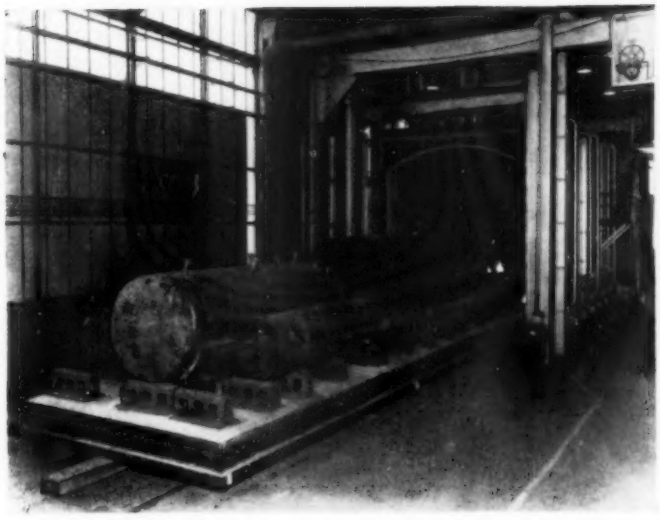
The magnet ring, which is being made in 336 sectors at the rate of six a week, will, when completed, have a diameter of 160 ft. Each sector stands 10 ft. 5 in. high, is 9 ft. 3 in. wide, and 12½ in. thick, and weighs nearly 20 tons. Accuracy in parts is to 0·005 in. and each sector must be tapered to one-half of one degree to ensure perfect fit.

Annealing problems

One of the most difficult of the operations required to produce the magnet sectors proved to be the annealing of the plates. Annealing is necessary to flatten the plates, homogenize their structure, and optimize their electrical properties, and the treatment consists of heating a stack of plates in a bell-type furnace to a temperature of around 800 C. and cooling them again. Difficulties arose because the plates are roughly 10 ft. square, and it would be all too easy to raise or lower the temperature of one part of a plate too quickly, causing unequal expansion or contraction, which would result in buckling. Much experimental and development work had to be carried out before a satisfactory annealing procedure was established. As finally developed, the furnace system has three sets of electric heating elements; in the furnace bell, in the hearth, and in a special throat-heating block.

Another problem which had to be overcome was the effect of 'crowning' of the plates. An unavoidable defect of the rolling process, crowning, which causes the plates to be slightly barrel-shaped in cross-section, can be ignored for most purposes, but had to be taken into account in annealing the magnet plates. As the amount of crowning varies from cast to cast, tables have been worked out for compensating for this effect over a range from 0·002 to 0·012 in. thickness variation between centres and edges. Compensation is made by inserting at specified positions within the stack of plates pieces of cold-reduced strip 0·013 in. thick and from 3 to 18 in. wide.

Plates are stacked, on top of each other, on a flat base of 1-in. mild steel until a height of 4 ft 3 in. is reached; compensation pieces are inserted as



Heat treatment at Babcock & Wilcox Ltd.

1 *Stress relieving and annealing furnace in the drum shop*

BABCOCK & WILCOX LTD., makers of steam boiler plant, a member of the English Electric—Babcock & Wilcox—Taylor Woodrow atomic power plant consortium, has works at Renfrew and Dumbarton, where furnace plant for hot working and accurate heat treatment is essential for almost every item of manufacture. In 1958 two million therms of town gas were used in these factories.

The Renfrew works, which covers an area of 165 acres and employs 8,000 persons, manufactures the pressure vessels, superheaters, heat exchangers, headers, manifolds, and pipes, etc., that make up power station plant, and, more recently, nuclear power plant. Much of the work is large and bulky; much also is of welded fabrication or construction which must be suitably heat treated to fit it for its arduous duty.

Drum shop

The Dowson & Mason Ltd. stress relieving and annealing furnace, shown in fig. 1, is of the bogie-hearth type with internal dimensions, width 14 ft., length 38 ft. 3 in., height 12 ft. 2 in. (top of bogie to spring of arch).

The furnace is designed for stress relieving at 600—650° C., with occasional annealing at 900—950° C. It handles the large drums and cylinders that have been formed and welded using steel plate of up to 5 in. thickness and more, and often having undergone further welding operations through the addition of pipe connections and other attachments. The figure shows a typical load ready to be hauled into the furnace.

The 14-in. walls are of 9 in. of insulating refractory with a backing of 4½ in. of diatomaceous insulation, the insulating refractory being threaded on individual short rods staggered at intervals and secured to the steel casing. The arch also is of insulating refractory and diatomaceous insulation, together with Vermiculite loose fill. The whole internal surface of the walls and roof is coated with a brick seal bonding mortar.

The door consists of structural steel members provided with clamps and lined with lightweight insulating refractories threaded on vertical steel rods in a similar manner to the construction of the side walls. The door traverses sideways on a single-beam overhead runway electrically operated from pendent chains. It is provided with lips at top and bottom which run in sand seals over the arch and at the end of the bogie. Additionally, asbestos pads are fitted so that when the door is clamped against the face of the opening there is a positive seal preventing gas leakage.

The bogie top is constructed with a number of shallow grooves in which 9 in. high heat-resisting iron castings for supporting the load are placed. The brickwork of the top of the bogie is of Glenboig firebrick 4½ in. thick over a layer of 3 in. of insulating refractory and a bottom layer of diatomaceous insulation. Heavy cast iron sand troughs are arranged round the front and two sides, with a movable sand seal trough at the back to prevent air infiltration. The movable trough is automatically operated by the bogie.

Electrically-driven haulage gear is provided for moving the bogie in and out of the furnace and a limit switch is incorporated to prevent overrun of the bogie, so that even if the operator is careless it cannot crash into the back wall. Furthermore, the controller is connected with a limit switch on the furnace door traversing gear which ensures that the door is in its fully open position before the bogie is moved into or out of the furnace.

The furnace has 60 gas burners, 30 on each side at hearth level, firing alternately, horizontally, and vertically (the flame being deflected upwards by a tile in front of the burner). The burners are of the nozzle-mixing type, using air at 5 in.w.g. and have a maximum rated capacity of 60 therms/h., the gas supplied to the Renfrew works having a nominal calorific value of 425 B.Th.U./cu. ft.

Waste gases pass through flues at hearth level which are joined together and connected to underground cross flues to meet the main flue.

Instrumentation. The furnace, for temperature control purposes, is divided into three zones. In each zone there are the following fully floating temperature controlling and recording devices:—

(1) An 8 ft. long control thermocouple projecting through the roof, raising and lowering gear being provided to lift it clear when the charge is moved. This is connected to an Electroflo potentiometric recording controller which actuates gas and air valves in that particular zone by means of a hydraulically operated regulator.

(2) Three thermocouples, one through the roof and one at each side approximately 4 ft. above bogie level. These are connected to multipoint temperature recorders.

Automatic furnace pressure control is effected through the main flue regulator, and registered by the pressure recording controller.

Performance. Designed capacity is given in Table I and the results of two tests are given in Table II.

In Test No. 1 the charge consisted of 3 drums, total weight 70 tons. The heating cycle was a primary stress relief at a temperature of 625°C., the stipulated holding period being not less than 3 h. In Test No. 2 the charge was again 3 drums, total weight 91·1 tons. The heating cycle was a primary stress relief of high tensile steel drums at a temperature of 600°C., the stipulated holding period being not less than 2 h.

TABLE II *Results of two performance tests*

		Test No. 1	Test No. 2
Weight of charge	tons	70	91·1
Temperature	°C.	625	600
Gas used (excluding soak)	therms	680	645
Time to reach holding temperature	h.	11·25	10·8
Gas used (excluding soak)	therms/ton	9·7	7·1

Tube and manifold department

In the tube and manifold department, heat treatment is carried out with a Dowson & Mason furnace of the bogie type, having inside door width of 10 ft. 6 in. by 4 ft. high from the top of the piers on the bogie to the spring of the arch, and a length of 40 ft. 3 in. The bogie is 10 ft. 3 in. wide by 40 ft. long.

The furnace was designed for normalizing, annealing, and stress relieving. Manifolds are $\frac{3}{4}$—$1\frac{1}{2}$ in. thick and range in size from 6—$7\frac{1}{2}$ in. square and 10—20 in. dia., length up to 40 ft. and more. They are manufactured by hot extrusion, the ends are closed by hot swaging, and much machining and welding is finally performed. Stress relieving, therefore, is important. Mild steel is stress relieved at 650°C., and alloy steels at temperatures up to 725°C. Superheater and economizer tube banks, which undergo bending and other hot working, are annealed or normalized, according to requirements, at temperatures between 920°C. and 950°C.

The walls and roof of the furnace are of light weight insulating refractories 9 in. thick. To allow an adequate cooling rate, no diatomaceous insulation is used. The inside faces of the lining are coated with a refractory cement.

The door, made up of cast iron sections, is lined with insulating refractories held by mild steel rods. There is a removable portion with an opening about 2 ft. square to enable manifolds longer than 40 ft. to be treated. The door is counterbalanced, but operated by a hydraulic cylinder and interlocked with the bogie haulage mechanism so that the bogie cannot be moved until the door is open.

TABLE I *Design figures and estimates based on heating the furnace and charge from cold*

Weight of charge	tons	50	50	100	100
Temperature	°C.	620	940	620	940
Gas required (excluding soak)	therms	485	1,080	800	1,750
Time to reach holding temperature	h.	8·75	19·5	14·5	31·25
Heat input at holding temperature	therms h.	22	45	22	45
Gas required (excluding soak)	therms/ton	9·5	21·6	8	17·5

The relatively small requirements for annealing at the higher temperature did not justify the provision of larger burner equipment to reduce the time required for that treatment.

The top of the bogie is of 4½ in. firebrick built on 3 in. courses of insulating refractory and diatomaceous insulation. Heat-resisting steel load supports are used, similar to the iron supports for the Drum Shop furnace. Electric haulage gear is fitted in a pit below floor level.

The furnace has 60 burners, 30 at hearth level on each side firing alternately, horizontally and vertically with a maximum rated capacity of 64 therms/h. Those firing horizontally are nozzle-mixing burners and those firing vertically are luminous flame burners, air being supplied at 8 in.w.g. The luminous flames are obtained by slow mixing of the air and gas streams and avoid the production of high heat intensity at the base of the side walls. This is important because of the necessity to obtain very close temperature uniformity over the whole of the furnace.

The waste gases are exhausted through a number of flues at bogie hearth level arranged along the side walls. These are connected to horizontal flues below the furnace, which in turn pass into the main flue and to a separate chimney built at one side of the furnace.

Instrumentation. The furnace is divided into three zones each controlled by George Kent Ltd. fully floating pneumatic recording controlling equipment connected to thermocouples in the furnace roof. These instruments operate air-gas proportioning valves in each zone. In addition, thermocouples in the side walls are connected to a six-point recorder. Automatic furnace pressure control is effected through the pneumatically operated main flue damper. A gas flow recorder is included in the instrument panel.

Performance. The furnace is designed for a load of the order of 30 tons excluding the stool castings and estimated figures are given in Table III.

The figures given in Table IV are taken at random from the daily records of normal operation in which, after each charge is heated, the furnace is cooled down almost to atmospheric temperature before a charge is inserted on the following day. Net figures are given for the weight of charge, but each includes, in addition, 4·9 tons of support castings.

TABLE III *Estimates based on heating the furnace and charge from cold*

Weight of charge	tons	30	30
Temperature	°C.	650	950
Gas required (excluding soak)	therms	327	870
Time to reach holding temperature	h.	6	14
Maintenance heat input at temperature	therms/h.	13	39

Pipe shop

In the pipe shop the stress relieving and annealing furnace, built by Dowson & Mason Ltd., is again of the bogie hearth type, and has internal dimensions, width 10 ft. 6 in., length 22 ft., height 5 ft. (top of bogie to spring of arch).

The capacity of the shop includes pipes ranging from 4½ in. to 18 in. dia., and from ⅜ in. to 2 in. thick, all solid drawn tube. The furnace is used for the heat treatment of bends, and flange and branch welds. Mild steel is stress relieved at 650°C. Alloy steels, after welding are stress relieved at 725°C., or, after hot bending or forging, annealed or normalized, according to specification, at temperatures of 915—920°C.

The furnace has walls of 9 in. insulating refractory backed up with 4½ in. diatomaceous insulation and the roof is of 9 in. insulating refractory and 3 in. diatomaceous insulation with Vermiculite loose fill. Heat-resisting iron pier castings are used for supporting the load as on the furnaces previously described. There are 30 nozzle-mixing air-blast burners in the furnace, 15 on each side, half of them firing vertically and the other half firing horizontally between the stools on the bogie. The maximum rated capacity is 32 therms/h.

The furnace is fitted with George Kent Ltd. fully floating pneumatic recording controlling tempera-

TABLE IV *Representative data of normal operation*

	Weight of charge tons	Time to heat h. min.	Soaking time h. min.	Gas consumption therms	Gas consumption therms/ton
Operation at 650°C. with ½-h. soaking periods	8	2 45	30	175	21·9
	12	2 10	30	166	13·8
	30	3	30	218	7·3
	34	2	30	180	5·3
Operation at 650°C. with more than 1-h. soak	13·25	2 35	1 20	259	19·5
	16·45	3 15	1 15	225	13·7
	20·6	3 20	1 20	268	13·0
	23·1	3 15	2	298	12·9
Operation at 710°C. with ½-h. soak	6	2 40	30	196	32·6
	42	3 30	30	296	7·0

ture equipment operating proportioning combined gas and air valves, the furnace being divided into two zones. The controlling thermocouples are arranged in the arch and fitted with raising and lowering gear. Automatic furnace pressure control is effected through a butterfly damper operated pneumatically.

The furnace was designed for a load of 12 tons, excluding support castings, and the makers estimated that a full load would reach 920° C. in 6 h. with a gas consumption of 16 therms/ton.

Steel foundry

The portable cover annealing furnaces, shown in fig. 2, are used for the annealing of iron and steel castings at temperatures of 680° C. and 950° C. respectively.

The installation by Dowson & Mason Ltd. consists of two bases, each 4 ft. 9 in. wide by 9 ft. 9 in. long, and a removable hood lined with lightweight insulating refractory. The height from the hearth to the roof of the hood is 5 ft. 3 in. With one hood and two bases, a load being stacked on one base while another is being heated on the second base covered by the removable hood, almost continuous operation can be obtained.

The hearths are constructed of firebrick tiles covered by flat cast plates which protect the firebrick from damage which would otherwise result from the loading of a great variety of castings, some of which have sharp edges. Each base will take a load of 8 tons of castings and is equipped with 14 burners arranged along the two long sides, the burners projecting highly luminous flames vertically upwards. The waste gases pass off at each end through ports in the hearth, and through thimble type recuperators of calorized mild steel, preheating the air for combustion before passing to the chimney.

Electroflo two-position temperature control equipment is fitted, the control thermocouple being placed in the roof of the cover. The control instrument is connected to two valve regulators which operate the gas and air valves of each base. Other thermocouples are connected to a six-point temperature recorder.

The makers' estimate of performance taking a typical load of 4 tons as a basis is given in Table V.

Header factory

This is the shop that produces the header tubes which pass to the Tube and Manifold Department for further working, and which were mentioned earlier when describing the work of that section.

The circular tubes, of 10 to 20 in. dia. and $\frac{3}{4}$ in. to $1\frac{1}{2}$ in. thickness, are closed by a swaging process after the tube end has been heated to 1,100—1,200° C.

Two identical furnaces of Babcock & Wilcox design are in use for the tube end heating. In each, the working chamber is a horizontal cylinder, 3 ft. dia. by 2 ft. long, closed at one end. The tube is inserted at the other end through a circular opening, the diameter of which can be varied by the use of refractory rings appropriate to the size of tube. Dense refractories are employed in the construction, and the furnace operates with a wall temperature in the order of 1,400° C.

The furnace has two tangentially-firing burners spaced 180° apart on a circle midway between the two ends of the chamber. The burners are of the nozzle-mixing type with a centre air jet from which the air issues with a swirling motion into a short combustion tunnel. Air is supplied at 28 in.w.g. and the maximum gas rate of each furnace is 20 therms/h.

Tube annealing at Dumbarton

The Dumbarton works is a tube works, manufacturing the high quality material that the Renfrew works transforms into boiler tubes and superheater nests. The sequence of furnace plant is: (i) Billet heating furnace; (ii) reducing mill furnace and (iii) tube annealing furnace.

Tube from the reducing mill is subsequently cold drawn to its finished size, but before this operation, at successive stages of drawing and again on finishing, the tube is annealed.

A Dowson & Mason continuous roller hearth furnace providing this treatment is shown in fig. 3 giving a view at the charge end. Tubes are heated to 950° C. and cooled to 500° C. before being discharged.

The total length inside the furnace is 88 ft. The first 20 ft. is the heating zone, the next 10 ft. the soaking zone, and the remaining 58 ft. the cooling zone. The width of the furnace inside is 4 ft., the effective loading width of the rollers being 3 ft. 10 in.

TABLE V *Estimated performance data of castings annealing*

		4 tons cast iron	4 tons steel
Charge			
Temperature	°C.	680	950
Gas required (excluding soak)	therms	42·5	85
Time to reach holding temperature	h.	3	5
Maintenance heat input at temperature	therms/h.	3·2	7·7
Total gas required, including ½- to 1-h. soak	therms/ton	11·5	22·2

Burners are arranged to fire both under and over the roller hearth from both sides and a flue is taken off at the charging end of the furnace. All rollers in the furnace and on the charge and discharge tables are driven through variable speed gears. In this way the tube is carried through the furnace at a speed which will ensure its proper treatment.

The whole of the heating and soaking sections, walls, roof and bottom, are constructed of 9 in. of lightweight insulating refractory backed by 3 in. of diatomaceous insulation.

Automatic proportioning air-blast tunnel burners using air at 28 in.w.g. are employed. In the first zone, the heating zone, there are six burners on each side, four firing under the rollers and two firing over the rollers. Each of these burners has a gas rate of 2½ therms/h. The soaking zone has three burners on each side, two below the rollers and one above, each only half the size of those in the heating zone. The total maximum gas rate of the furnace is 37½ therms/h.

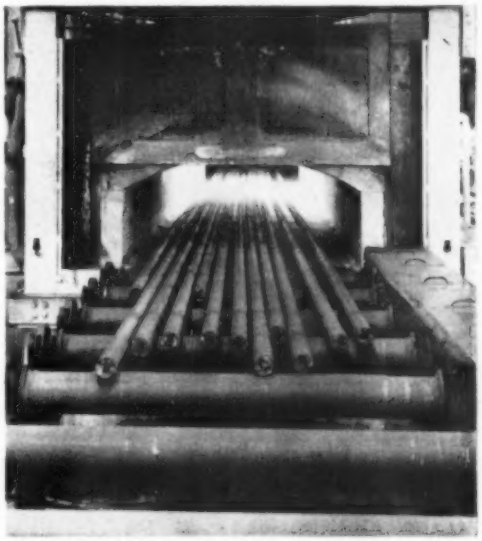
The rollers within the furnace consist of 5 in. dia. heat-resisting steel tubes connected on the driven side by muff couplings to the driven stub shafts of mild steel rotating in split race roller bearings. The chain drive arrangement allows any roller to be removed while the others still rotate. All are fitted with seals to prevent leakage of hot gases or air infiltration.

The rollers of the charge and discharge tables are of similar design, but use a mild steel roller tube.

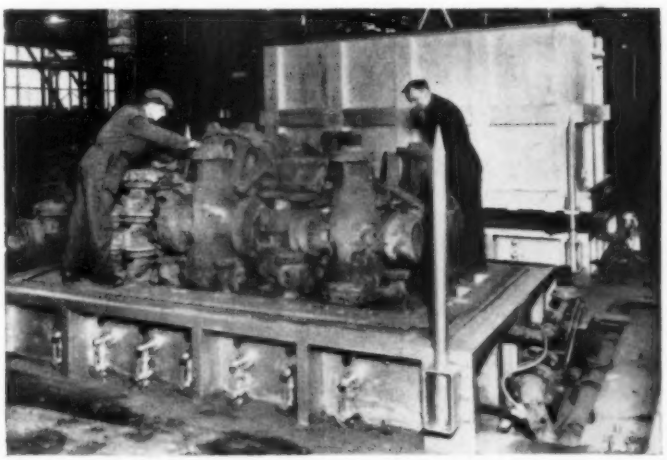
This is designed gradually to cool the tubes to a temperature lower than 500° C. before discharge. The side walls above the rollers, and the arch, are constructed of 4½ in. firebrick to dissipate the heat. A mild steel duct through which air for combustion is drawn is arranged behind the side walls. This assists the cooling and provides a small air preheat.

Instrumentation. The heating and soaking zones each have Electroflo fully floating temperature control equipment with hydraulically operated furnace valves. In addition, six thermocouples are connected to a six-point recording pyrometer.

Design capacity. The furnace is designed to heat tubes to 950° C. and cool to 500° C. before discharge, tube sizes varying from 1½ in. o.d. to 3¼ in. o.d. and weight per foot from 2 lb. to 9½ lb., output 2 tons/h. Some of the tubes are distorted when charged and a loading factor of 75% across the rollers has been



3 ABOVE *Charging end of roller hearth furnace for continuous annealing at Dumbarton*



2 LEFT *Portable cover annealing furnaces for castings at the Renfrew works*

allowed. The design loading was 10—3½ in. dia. tubes or 23—1½ in. dia. tubes across the width of the furnace. The roller speed can be adjusted to give a linear speed of from 0·65 to 3·9 ft./min.

Performance. Average performance figures for continuous operation throughout the week are given in Table VI.

TABLE VI *Average performance figures of roller hearth furnace*

Steel	Temperature °C.	Throughput tons/h.	Gas consumption therms/h.	Gas consumption therms/ton
Mild steel	800	2	16·2	9·5
Alloy steels	920	2·25	18	11
	935	1·75	18·5	12·5

A bogie hearth tube annealing furnace, designed for the heat treatment of alloy and mild steel tubes of maximum length 50 ft. at temperatures between 650°C. and 950°C., is of similar design and construction to that in the Tube and Manifold Department at Renfrew. It has, however, a door at each end and employs two full length bogies so that one may be loaded while the furnace is treating the work on the other. The inside door width is 9 ft. 3 in., and the length 54 ft. The walls are of 9 in. of insulating refractory backed up with 4½ in. of diatomaceous insulation. On the bogies there is 4½ in. of firebrick over layers of 4½ in. of insulating refractory and 4½ in. of diatomaceous insulation. As in other furnaces, the work is carried on cast stools, but because the furnace is frequently used in the higher temperature ranges, they are of heat-resisting steel.

There are 80 burners, 40 at hearth level on each side, firing alternately horizontally and vertically, with a maximum rated capacity of 90 therms/h.

For control purposes the furnace is divided into four zones each zone being provided with Electroflo fully floating temperature control equipment, comprising an electronic recording and controlling potentiometer which operates air and gas proportioning valves through hydraulically operated regulators. The furnace is also provided with two six-point recording pyrometers connected to 12 thermocouples arranged at different positions in the furnace.

The waste gases from the furnace are taken away through an underground flue and the furnace pressure is controlled and recorded by Electroflo instruments. An electrical transmitting type recording and integrating ring balance flow meter is also provided.

A few production figures are given in Table VII.

Acknowledgment

The data in this article have been reproduced from Report No. 700/59 of the Industrial Gas Development Committee of the Gas Council (Information supplied by the I.G.D.C.).

TABLE VII *Performance of bogie-hearth furnace*

Operating temperature °C.	Weight of charge tons	Time to heat h. min.	Soaking time min.	Gas consumption therms	Gas consumption therms/ton
800	9·93	4 0	30	333·9	33·6
850	10·89	4 15	30	387·3	35·6
900	9·63	4 35	30	381·3	39·6
920	10·63	4 55	30	430·8	40·5

Silicon manufacture

Earlier this year I.C.I. announced the bulk production of semi-conductor grades of silicon from their plant—the first in Britain, and it was stated there were plans for expanding the capacity still further to 4,000 lb. The extension has been completed, and the benefit of increased production is being passed on to the consumers by way of price reductions. The demand for silicon in Britain can be met and considerable quantities are being sold abroad so that extensions have been planned which will more than double capacity in 1960. These modifications will be made relatively simply as the original plant was designed for ready expansion.

Two distinct types of silicon are required at present by device manufacturers—lump or granular silicon, from which single crystals are made, and zone-refined silicon in rod form. I.C.I. have been actively working on methods of growing silicon rods suitable for zone-refining, and are now installing a new plant which will be producing polycrystalline rods early in 1960. The rods will have diameters up to 1 in. and lengths up to 24 in.

Change of name

In order to clarify the association with the parent company, the Morgan Crucible Co. Ltd., the name of Synthetic Carbon & Engineering Co. Ltd. has been changed to Morgan Components Ltd.

The capacity of this company at Stanmore has been enlarged and will be concentrated on the sales and production of all brush holders hitherto manufactured by the Morgan Crucible Co. Ltd. and Synthetic Carbon & Engineering Co. Ltd.

Morgan Components Ltd. will continue to manufacture and supply a variety of metal contacts and associated metal assemblies, which were formerly supplied by the Synthetic Carbon & Engineering Co. Ltd.

Enquiries and orders for carbon brushes and carbon contacts, formerly supplied by the Synthetic Carbon & Engineering Co. Ltd., should now be sent to the Morgan Crucible Co. Ltd., Battersea Church Road, London, S.W.11. The grades of carbon used will be as previously supplied, but the grade markings will conform to the Morganite series.

Gas-fired reducing furnaces for converting tungsten and molybdenum oxides to metal powder

Television tube and valve manufacture

Lancashire plants of Mullards Ltd.

The manufacturing plants of the Mullard Group are located in two main regions in the North and South of England. The northern plants, concentrated in Lancashire, are at Blackburn, Simonstone (near Burnley), and Southport, with a number of smaller feeder factories in Fleetwood, Rawtenstall, Lytham St. Annes and Southport. Between them the Lancashire plants account for about half the Group's 17,000 employees.

Last month a visit for the technical press was arranged by the Gas Council and the North-Western Gas Board in conjunction with Mullard Ltd. In the time available during the visit it was not possible to see the Southport plant, where magnetic materials and magnets are made, but only those at Blackburn and Simonstone. Brief accounts of the manufacture of receiving valves, and fine wire at Blackburn and television picture tubes at Simonstone are given here

SIMONSTONE

The Simonstone plant produces over 1½ million television tubes a year—a large part of the Group's total output. The plant, which has been described as the most modern of its kind in Europe, was built in 1954-55. Since then the plant has expanded considerably and now employs some 1,700 people, the majority of whom are men.

Manufacture of television tubes

The production of television tubes at Simonstone begins with the component parts of the glass bulb; the cylindrical neck, the flared cone, and the rectangular faceplate.

The neck is first welded to the cone by automatic rotary machines, of which there are six in the plant, each having 12 stations. The two parts are first pre-heated by radiant cup gas burners and gas-air burners to bring them to the correct temperature for welding and the weld is then made by oxy-coal gas jets. Following this, the bulbs are transferred to a side-sealing machine where the metal e.h.t.

connection is fused into the side of the cone. The region of the seal is pre-heated by radiant cup burners and gas-air jets, and the seal is made by oxy-coal gas jets.

The neck and cone assembly is then annealed and pre-heated ready for the faceplate to be joined on; the faceplate is also pre-heated to the same temperature. Twenty-four automatic machines weld the faceplate to the neck and cone assemblies. Gas-air jets pre-heat the two component parts, and cross-fires of oxy-coal gas jets further raise the temperature of the welding region. The actual weld is accomplished by an electric arc struck through gas flames which brings the edges of the two components up to melting point, when a perfect seal takes place.

The complete bulb is annealed and allowed to cool slowly. The bulbs are now introduced to the two-mile long overhead conveyor system that runs through the entire plant, and around which all the subsequent processes are planned.

The cooled bulbs are thoroughly washed with different solutions to make ready for the vital process of laying the fluorescent screen effected in rotary mills fitted with dispensers which automatically deliver the correct amount of buffer solution, water glass and fluorescent powder. The fluorescent powder gradually settles down through the buffer solution evenly on to the surface of the glass, where it is held by a gel-like formation produced from the different solutions. The bulbs are automatically tilted to remove the liquid, leaving the screen deposit undisturbed. The bulbs are dried by infra-red lamps and filtered air and are then given internal coatings of lacquer and graphite, the latter to form an electrical connection between the final anode and the e.h.t. connector.

The bulb is then ready for laying a film of aluminium by vacuum deposition on the inside of the screen and cone. The film acts as a mirror behind the fluorescent screen, increasing the brightness of the picture. It also prevents the screen being damaged by heavy ions during the tube's working life.

The bulbs are next passed slowly through one of two continuously operated 100-ft. long Lehr furnaces to drive off all moisture and to bake out the unwanted constituents of the various coatings, which would otherwise make it impossible to maintain the necessary vacuum in the finished tube. This baking process also fixes the fluorescent screen firmly to the glass face.

The electron guns are assembled in a separate part of the factory by highly trained female operators. The component parts (over 60 to each gun) are manufactured to very high standards of accuracy and a system of statistical quality control is applied throughout so that there is no possibility of faulty parts reaching the assembly operation. Oxy-coal gas jets are used in the assembly of the guns, to weld the glass support rods in the electrode assembly.

The assembled guns are checked by microscope to ensure that the spacing of the electrodes is correct. They are then washed to remove contamination before passing to the rotary sealing machines, which seal the gun, mounted on its glass base, into the neck of the bulb. The sealing machines for sealing the gun into the neck employ radiant cup gas burners for pre-heating the region of the join and oxy-coal gas jets for the actual seal.

After this operation the tubes are evacuated, during which the tube passes through a long, heated tunnel. This heating process drives off any gases present in the metal electrodes, the glass bulb, or the screen materials. At the same time, an electric current is passed through the heater to give the cathode the necessary emissive properties. These operations completed, the getter is 'fired' by induced high-frequency currents.

The tube is then connected to power supplies and its internal metal components are bombarded by electrons from the cathode to stabilize its performance, and is then subjected to a series of rigorous tests under working conditions.

BLACKBURN

Established shortly before the 1939 war, the Blackburn plant covers 46 acres of ground and employs nearly 5,000 people. It is responsible for most of the Group's production of radio and television valves, turning out about a million a week. Large sections in the plant are devoted to making fine wire, glass and components. Much of the glass and wire is absorbed by the valve manufacturing units of the plant but substantial quantities of tungsten and molybdenum wire are supplied to other industries for a variety of purposes.

Valve manufacture

The major part of the Blackburn plant is engaged in the manufacture of receiving valves, chiefly for radio and television. Apart from the mica spacers and the nickel used for some electrodes, all the components for the many different types produced are made within the plant from the raw materials.

The basic components of a valve are: the electrodes, comprising heater, cathode, anode and, excepting diodes, one or more grids; the glass envelope and base; the internal supporting members, mica spacers and insulators. These various component parts are fabricated in separate units of the plant and brought together in the large assembly bays where skilled operators build up the complete valves.

The cathode consists of a central core of nickel tube, round which the emissive coating is sprayed.

The nickel tubing is re-drawn in the plant's wire-drawing unit to the very small dimensions required in cathodes, which may scale only 0·75 mm. × 0·65 mm., with a wall thickness of 0·05 mm. The emissive coating, a mixture of barium and strontium carbonates in a volatile solvent, is sprayed on under careful control to ensure a coating of uniform density and thickness. Inside the central tube of the cathode is inserted the heater, or filament. This consists of a spiral of very fine tungsten wire formed into a ' V ' or ' M ' shape and coated with aluminium oxide to insulate it electrically from the cathode. The manufacture of heaters and cathodes calls for great delicacy and refinement to ensure high standards of performance and long life in the finished valves.

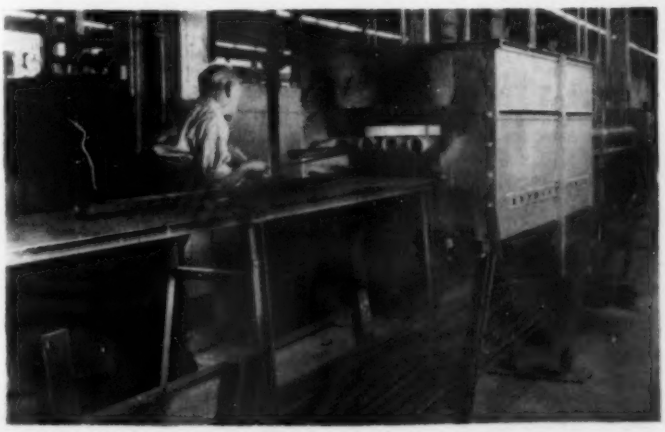
The grids of the valves are essentially flattened spirals of very fine molybdenum wire wound on stiff ' backbones ' or supporting rods. They are wound automatically on precision winding machines in lengths of about 4 ft. at a time, and each length is then cut into individual grids of appropriate size.

Anodes are pressed to the required shape and size by automatic machines from nickel, nickel-plated steel or aluminized steel, depending on the type of valve.

In the assembly bays operators, assisted by ingenious mechanical aids, assemble the electrodes into a ' cage,' ready to be mounted on the base. The base is a small disc of glass holding the connecting pins by which the valve plugs in to the valve-holder and a corresponding number of wires to which the various electrodes are connected. Joining the stiff metal pins and the thinner connecting wires is a third length of wire which has the same overall coefficient of expansion as the glass, and which, therefore, ensures a perfect airtight seal where the wires pass through the glass.

The machines that make the bases automatically feed the correct number of tri-metal connecting wires into a jig. A collar of glass is placed round the wires and the whole assembly is revolved. As it rotates, gas flames soften the glass collar and the machine gently presses it into shape around the centre sections of the tri-metal wires. Special machines then cut the connecting wires into the right lengths and bond them to the exact positions for the electrodes to be welded to them.

Once the electrode cage has been joined to the base, the next steps are to seal the assembly into its glass envelope and then to evacuate the air to form



ABOVE *Swaging operation used to form the sintered tungsten and molybdenum bars into thin rods ready for wire drawing*

LEFT *Stress relieving the wire is carried out at different stages of manufacture*

the vacuum necessary to the operation of the valve. Substantial quantities of gas are used in these operations. In the first, gas jets are employed to soften the glass at the junction of the base and the envelope before the sealing machine automatically applies the correct pressure to form the joint; and in the second for pinching off the pumping stem once the air has been removed. Twenty-four rotary pumping machines, each capable of handling 30 valves at a time, are in operation.

While the valve is being pumped, the metal components inside are heated by induced high-frequency currents to drive out any gases which may have been absorbed during manufacture. A current is passed through the heater to reduce the cathode coating to oxide, thus forming the electron emitting surface, and induced heat is again used to evaporate the getter to absorb the last traces of gas. When the valve has been removed from the machine it is operated for a period under controlled conditions. During this period changes occur in the cathode coating resulting in improved emission.

Finally, the valve is put through a succession of exacting tests covering its operating characteristics, emission, vacuum, insulation and so on. In addition to these routine tests, the quality control laboratory continually tests batches of valves selected at random from the production line. Any falling off in quality is detected at the earliest possible moment, so that steps can be taken to correct it before the trouble can assume serious proportions.

Making fine wire

A large section in the Blackburn plant is given over to the manufacture of tungsten and molybdenum wire. A substantial amount is supplied to other manufacturing industries for a variety of purposes.

The annual output of wire exceeds a quarter of a million miles. Most of it is extremely fine, down to a diameter of five thousandths of a millimetre.

Tungsten occurs naturally in the tungstates of iron, magnesium and calcium. It is the latter, known as scheelite, that is used at Blackburn. The quality of scheelite available from various world sources varies greatly, and skill and experience are necessary in its selection. Molybdenum is obtained from molybdenite ore, the chief deposits of which are in the American continent, Norway and Yugoslavia.

For tungsten wire, the scheelite ore is put through chemical tests to ensure its quality, after which it is ground continuously for several days in a ball mill. The resulting very fine tungsten oxide powder is purified chemically, and placed in reducing furnaces where, in a hydrogen atmosphere, it is converted to tungsten metal powder. The reducing furnaces, which run up to 900°C., are gas-burning. Controlled amounts of special additives are introduced into the pure powder to control its crystal structure and to prevent the finished wire sagging, and the powder is then compressed into bars of convenient size.

Next come sintering processes which crystallize the compressed powder into a hard metal, ready to be made into wire. Sintering is done by first heating the bars in an atmosphere of hydrogen and then passing through them an electric current of between two and three thousand amperes.

The sintered bars are swaged by raising them to white heat and hammering in successive stages until they take the form of thin rods. Gas furnaces are used to heat the bars prior to hammering.

The tungsten rods are drawn through a series of progressively smaller dies until they have been reduced to the thickness required. Drawing occurs in three main stages: first on a chain bench, next on large-diameter drums, and finally on smaller drawing heads. In each stage a number of dies are used, carefully spaced to achieve a gradual reduction in diameter and, at the same time, to increase the strength and ductility of the wire. Hard metal dies are used in the initial stages, but as the wire becomes thinner diamond dies are necessary. Gas is used extensively throughout the drawing operations, for heating the wire before it is pulled through the dies and also in the annealing furnaces through which the wire passes at pre-determined intervals to remove strains.

Once the required diameter has been obtained the wire is put through a series of strict tests and inspections to check its dimensional accuracy and mechanical properties.

Steel strip rolled from powder

A PROCESS FOR MAKING steel strip from iron powder has been announced by Republic Steep Corp., Cleveland, U.S.A.

The experimental process consists of three main steps: First, iron ore is purified and then reduced to iron powder. The powder is funnelled between four rolls where it is compressed into a semi-solid strip with sufficient 'green' strength to hold together. The compacted strip is heated to 2,200°F. in a furnace with a reducing atmosphere and is passed through a series of hot rolling mills. Hot rolling brings the compacted powder up to full density and gives hot rolled steel which has the same quality as conventionally-made steels. After coiling, the steel goes through the usual operations of pickling, cold rolling and annealing before being re-coiled or cut into sheets.

Republic has produced more than 1,800 lb. of low-carbon steel strip by the process. Plans are being made for a pilot line which will produce strip up to 12 in. wide on a continuous basis starting with powder. The process is adaptable to alloy steels as well as to low carbon steels.

Stainless steels

HARDENABLE 'AUSTENITIC' stainless alloys gained in importance last year, according to Mr. R. E. Paret, of the American Iron and Steel Institute, in *Metal Progress*, October, 1959. For example, the B-70 Valkyrie 'chemical' bomber, which employs one such alloy as the main sheet construction material, will travel at speeds up to 2,700 miles per hour without suffering damage from intense air-friction heat. In proper designs these hardenable alloys provide high strength and hardness with excellent resistance to corrosion. They have good formability, and can be hardened at temperatures low enough to minimize distortion and oxidation.

Low cobalt content in stainless steel for nuclear use is desired because of the ravaging influence of irradiation. Were cobalt content not restricted, corrosion products containing cobalt-60 could pose serious maintenance problems and hazards to personnel doing repair work. Cobalt-60 also may move out of the stainless alloy and contaminate the entire primary loop of the nuclear system. Now commercial quantities of austenitic Type 304L may be ordered with cobalt controlled to a value acceptable for use within the core of a reactor—perhaps as low as 0·005%.

A second development of significance to nuclear engineers is boron-treated stainless alloys. Type 304L with about 2% boron possesses high thermal neutron absorption, good structural stability at 260°C. under irradiation, and good corrosion resistance.

Until recently this alloy has not been commercially available. The metal was formerly melted in vacuum furnaces and heats were limited to less than 4,000 lb. Electric furnace melting can now produce heats of 24,000–28,000 lb.

A third stainless steel development may prove useful not only for nuclear reactors but also in other high-temperature applications. Nitrogen is closely controlled (0·3–0·5%) and chromium nickel and manganese levels are maintained at a 22:4:9 ratio. The alloy resists erosion, oxidation and corrosion at temperatures up to 870°C. Tensile strength exceeds 162,000 lb./sq. in. at room temperature. Rupture strength decreases to about 50,000 lb./sq. in. at 600°C. in extended service.

'Sandwich' rolling has progressed beyond the experimental stage. In this process several stainless plates are sandwiched between two carbon steel cover plates. After its edges are welded the sandwich is heated and hot-rolled on a conventional plate rolling mill. Typical sheets are 0·075 in. thick, 120 in. wide, and 240 in. long. Since the sheets do not contact the atmosphere during hot rolling and annealing, decarburization is negligible.

Stainless steel foil is available down to 0·0005 in. thick. Applications include honeycomb skins, electronic tubes, and missile and satellite instrumentation. Stainless foil 2 mils thick has been thinly coated with titanium activated with tritium for use as a radiation source.

Cold roll flowing of stainless steel offers weight reduction and better uniformity of mechanical properties in all directions. Like metal spinning, roll flowing contours parts by cold shaping over a mandrel. Roller pressures above 200,000 lb./sq. in. displace the stainless until it assumes the desired wall thickness and design contours. Frequently the process will reduce or eliminate need for machining or welding.

The narrow and variable band between yield point and ultimate strength in certain alloys prevents them from being formed by conventional methods. New stretch-forming equipment compensates for yield strength variations in these high-alloy stainless grades, and permits stretch forming without tearing of sheets. The ultimate answer, of course, lies not in machine refinements but closer control of yield strength variations by steel producers. Progress is being made here.

MAGNESIUM ALLOYS

ALTHOUGH alloys containing aluminium and zinc continue to be the backbone of the U.S. magnesium industry, several new compositions and the operation of a modern rolling mill and extrusion plant (Dow Metal Products Co., Madison, Ill.) are stimulating the use of magnesium in commercial applications. The new facilities produce sheet and plate, both flat and coiled, in widths ranging up to 72 in.

The extrusion plant is equipped with presses of 250–5,500 tons capacity and a heavy press of 13,200 tons capacity.

Magnesium alloy AZ31B (3% Al, 1% Zn) is employed as tooling plate. Available in thicknesses from $\frac{1}{4}$ to 6 in., it costs less than other lightweight tooling metals. Flatness of the as-rolled plate is satisfactory for tooling purposes. Magnesium treadplate, also rolled directly, is made into duck boards, platforms, and mechanical handling equipment where strength, light weight, ruggedness and long life are required.

Alloy ZE10A (1·7% Zn, 0·17% rare earth metals) is a new sheet composition. Unlike AZ31B, stress-relieving after welding is not necessary. This advantage, when combined with the good strength (38,000 lb./sq. in. tensile, 28,000 lb./sq. in. yield, 15% elongation) and the excellent weldability of the alloy, promises high productivity of large structural assemblies.

INSTRUMENTATION

Mass spectrometer

Metropolitan-Vickers Electrical Co. Ltd. has just completed the first production model of the MS7 mass spectrometer. The instruments now being produced are for the National Physical Laboratory, the Services Electronics Research Laboratory, the Mond-Nickel Co. and the U.K.A.E.A. Recently, orders for this instrument were also received from France and America.

The MS7 mass spectrometer has been designed specifically for the purpose of measuring minute impurities in solid substances using the spark ionization technique. It will be of invaluable use in fields of science and engineering where it is essential to use materials of the highest purity, such as nuclear engineering, semi-conductor research and manufacture, and in the development of non-ferrous metals and alloys.

Some of the materials which have been successfully analysed down to 0·01 p.p.m. with the prototype model include uranium, reactor-grade graphite, germanium, selenium, silicon, gallium-arsenide, magnesium, titanium, tungsten, iron, copper, aluminium, tin and nickel-chromium alloys.

Electron diffractograph

The Trüb, Täuber electron diffractograph KD3 has been designed for universal application. Problems in crystallography, physics and metallurgy can be solved using the basic apparatus with standard components. By the fitting of additional parts, the diffractograph is readily adaptable to users' special requirements.

Diffraction patterns can be observed on a luminous screen or recorded on photographic plates or films. A special device which is motor-driven, permits the continuous recording of structural changes as a function of temperature of the object.

The specimen can be etched under vacuum by ionic etching bombardment. A special ion gun of high current intensity with seven beams is designed for this purpose.

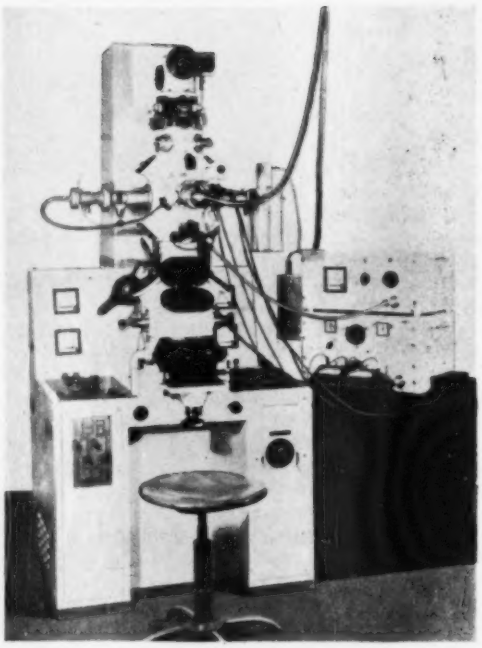
It is of great importance in this type of investigation to be able to observe the changes in the diffraction pattern as successive layers of the specimen are etched away. By operating the ion gun simultaneously with the moving film the progressively changing surface structural pattern may be recorded.

Comprising a tube for the electron beam with vacuum equipment and high voltage rectifier, the basic equipment permits recording of diffraction patterns from layers and surfaces, using the so-called transmission and reflection method at room temperatures. Accessories, provided for influencing the object during tests, consist of a specimen holder for heating the object up to 900°C. and a device for cooling the specimen to low temperatures. The diffractograph is so designed that the specimen holders will move the object into any desired position and rotate it about its axis during operation and without interrupting the vacuum. For direct viewing of the specimen an optical microscope is available with a magnification of ×200.

When working with semi-conductors and insulators the effect of loading on the diffraction pattern may be eliminated by the use of slow electrons from a separate discharge device.

Evaporation of metals in the diffraction chamber can be utilized to produce the thin evaporated layers without exposing them to the atmosphere.

The Trüb, Täuber cold Induni cathode with an accelerating voltage between 20 and 50 kV., the vacuum equipment with a special oil diffusion pump, and the clear and simple arrangement of the controls make the electron diffractograph very efficient and reliable. The electron optical accessories in the apparatus make it possible to observe micro-diffraction as well as electron optical magnification of the object of about ×70.



1 *Trüb, Täuber electron diffractograph*

Also manufactured by Trüb, Täuber is an electron emission microscope for the investigation of metallic and semi-conducting specimens by direct viewing and an NMR-spectrograph for high resolution.

Sole agents of Great Britain for Trüb, Täuber & Co. Ltd. are H. Tinsley & Co. Ltd., Wendee Hall, South Norwood, London, S.E.25.

Improved flow metering

Honeywell Controls Ltd. have recently raised flow and liquid level metering accuracies by installing a new high-performance diaphragm on their differential converter transmitters. The 'pneumatic balance' differential converter, which previously contained a Fluon-coated diaphragm separating high- and low-pressure chambers, now uses 'Viton' as a diaphragm coating.

Honeywell's production engineers have found that the new diaphragm provides better long-term stability of measurement and higher stability under varying temperatures. The chemical resistance of the new diaphragm is good, and it can be used to meter alkalis, amines, hydrocarbons and dilute or concentrated mineral acids. The Teflon-coated diaphragm remains available as an option for metering substances which might attack the new diaphragm.

NEW PLANT

High-temperature sintering furnace

A new heavy-duty sintering furnace for operation at temperatures up to 1,650°C. with a hydrogen atmosphere has been designed and manufactured by Royce Electric Furnaces Ltd. for a special application (fig. 1).

The heating chamber is a replaceable tube of fused alumina 5 in. inside diameter, 32 in. heated length. Fused alumina tiles housing the heavy section molybdenum heating elements surround the tube along the heated length and also support the tube, allowing free dissipation of heat and providing mechanical strength. A special high-temperature insulation of porous alumina behind the bricks is backed by graded thermal insulation, reducing heat losses to a minimum.

This design is a great improvement upon the molybdenum wound refractory tube usually used in this type of furnace. A mechanical failure of the work tube due to thermal shock or stress from the charge load does not, with this new arrangement, cause failure of the heating elements. Conversely, the work tube is unaffected by an electrical failure of the elements, which can be replaced individually in the segmental pure alumina tiles. A further advantage of this new design is that considerable sensible heat is absorbed in the refractory lining, acting as a heat reservoir. This serves to even out the heat distribution and coupled with the mechanically strong construction makes the furnace very suitable for heating heavy loads.

The cylindrical furnace casing is constructed of heavy-gauge mild steel plate, with removable end covers, the whole being gas-tight. At the charging end an extended solid drawn tube acts as a preheat-purging chamber; the exit chamber is water cooled to ensure that a charge is below oxidation temperature before leaving the furnace.

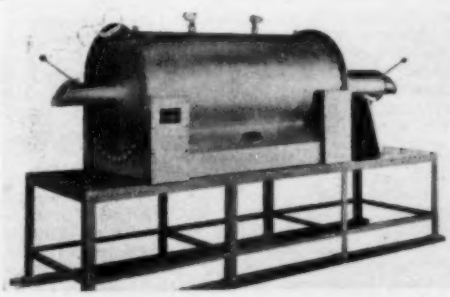
Atmosphere of hydrogen or cracked ammonia is fed through an inlet under the furnace to distribution pipes in the thermal insulation in the base. The gas percolates through the insulation absorbing heat and is, therefore, preheated before entering the work tube. Auxiliary inlets are provided in the main furnace casing and between heating and cooling chambers to allow an increase in the gas flow when doors are opened for charging or discharging. A 'burn-off' at both doors consumes excess hydrogen and prevents ingress of oxygen.

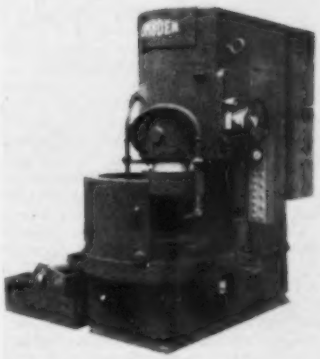
Heating is divided into two independent, automatically-controlled zones along the length of the heating chamber. Automatic temperature control, mounted in a separate control desk, comprises three positions, indicating type temperature controllers operating motorized voltage regulators giving stepless variation of the low-voltage element supply. By this means the current is not switched off when controlling at the pre-set temperature. The secondary voltage of the motorized regulator is automatically adjusted so that the power input to the furnace balances the consumption. This method gives a very smooth control eliminating fluctuations that may be obtained with 'on-off' control. Similar units are in operation with transductor control. Provision is included for hand control when required.

The furnace is rated at 25 kW. and is arranged for operation on a three-phase supply.

A charge of piece parts in alumina powder in a carbon boat 12 in. long has a gross weight of 14 lb. The boats are progressed through the preheat, heating and cooling chambers by a hand pusher or by a cycle-timed automatic pusher ensuring repeatability of the sintering cycle.

1 *Heavy-duty sintering furnace*





2 *Surface-grinding machine*

Surface-grinding machine

The 90ML is the latest addition to the Lumsden range of grinding machines. This machine incorporates a new automatic feed control to the wheel spindle ram. With this mechanism it is now possible to preset accurately the amount of stock to be removed. For example, if 0·050 in. is to be removed and the estimated ratio of stock removal to wheel wear is 10 : 1, the trip dial is set to 50+5, *i.e.* 55, and the feed-rate adjuster, set to any one of ten feeds, according to surface area and material to be ground. The trip dial turns as the wheel descends so that it shows the amount the wheel still has to feed. The feed stops when the trip dial registers zero. A second dial is provided for setting and adjusting the trip mechanism, this dial is graduated in very widely spaced 0·001 in. divisions.

Another development on this machine is an important new safety device which ensures that should the current to the magnetic table fail, a relay starts the elevating motor of the wheel spindle ram in the upward direction and all other motors stop. Thus the wheel is clear of the work before the residual magnetism has decreased sufficiently to allow the work to be thrown off the table as it slows to a stop.

Other electrical interlocks are provided to ensure

safety of operation, for example, the feed handwheel must be pulled outwards before the feed motor can be started—this ensures that there is no danger of a blow from the spokes of the handwheel and that the 'down' button is inoperative should this be pressed instead of the 'feed start.' Another interlock ensures that the magnetic table must be energized before the spindle motor can be started.

Alfred Herbert Ltd., Coventry, are sole agents for the Lumsden range of surface and tool grinding machines in the U.K.

Packaged oil-gas plants

The Incandescent Heat Co. Ltd., of Smethwick, England, report their development of a new process for the gasification of petroleum oil. The process is continuous and does not employ catalysts. Cracking heat is supplied by burning oil and waste products in a compact and simple furnace setting. The oil to be gasified is injected together with steam into a system which is specially designed to enable a uniform and precise control of cracking temperatures to be exercised. By these means the production of unwanted by-products (particularly carbon and tarry condensates) can be kept to a minimum; more particularly the calorific value of the gas produced can be varied continuously in the range 500 to over 1,200 B.Th.U./cu. ft. The gas is interchangeable with natural gas or coal gas of similar calorific value. Results obtained with a heavy distillate oil indicate that this system can be operated economically over a wide range of throughputs.

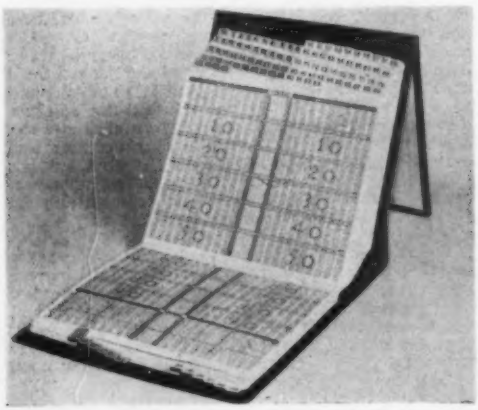
Decimal desk calculator

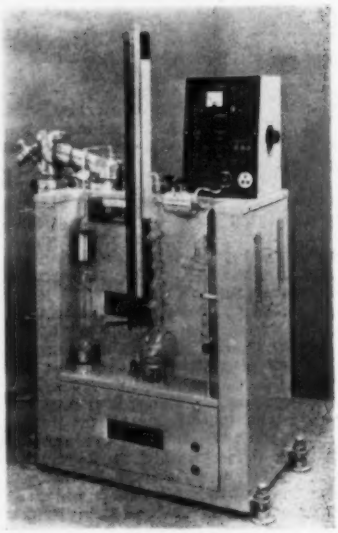
A desk calculator, which can give the results of calculations speedily and accurately, has recently been introduced into this country. Manufactured in Switzerland, it is based on a system which has been in use on the Continent for a number of years.

The calculator (fig. 3) is made in card index form and has 99 pre-calculated tables whose range goes from 1 up to 9,999. As the decimal point can be shifted at will in any direction the range would, of course, comprise digits such as 0·0001 and 9,999,000. Zeros can also be added as desired. Each of the 99 tables has an indicator tab denoting the prefix number of the respective table, *i.e.* from 1 to 99. It can be used for practically an unlimited variety of calculations.

Operation of the calculator can be learnt in a very short time. It has been successfully applied to complicated costing and estimating problems where the basic amounts are not greater than five significant figures. Weighing 7 lb., it works noiselessly and requires no repair. It can easily be carried from one place to another and is used only with one hand while the other hand writes down results.

3 *'Unical' card index-type calculators*





4 *Vacuum fusion plant for gas analysis*

Vacuum fusion gas analysis of metals

Gas analysis of metals by vaccum fusion is now a widely known technique throughout the industry and has many advantages over conventional wet methods of analysis. The latest production version of the vaccum fusion apparatus produced by Edwards High Vacuum Ltd., Manor Royal, Crawley, Sussex, is highly advanced equipment for macro determination of gases in steel and other metals, and the prototype was tested by the British Iron and Steel Research Association for several years.

The apparatus is exceptionally compact and glasswork has been reduced to a minimum. The most modern vacuum pumps and vacuum engineering methods have been used, resulting in a number of novel features. The major advantage concerns the use of the 'Speedivac' 2M4 mercury diffusion pump which has a high compression ratio. With a limiting backing pressure of 35 torr the 2M4 can extract a large mass of gas from the furnace and compress this into a very small collecting space. Its high pumping speed, 75 l./sec., also ensures that this gas is extracted quickly, thus reducing the 'getter' effect from evaporated metal films. A further advantage of such a system, using a small collecting space, is the absence of large surface areas, thus reducing a source of additional outgassing.

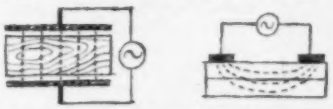
Nash & Thompson's new factory

Nash & Thompson Ltd. have acquired a second factory at Hook Rise, Tolworth, within 200 yards of their present research and production unit in Oakcroft Road, Chessington, Surrey. This new factory has increased the available space by 35,000 sq. ft. and the transfer of administrative departments, research and development and some production departments has now been completed.

Electrical Aids in Industry *Data Sheet* **No. 10**

Dielectric Heating - 1

When an electrically non-conducting material is placed between two metal plates, called electrodes, connected to an A.C. supply, the alternating electrostatic field between the electrodes considerably speeds up the molecular movements in the material (termed a 'dielectric') as a result of which the temperature of the material under treatment rises. A similar effect is produced



where the two electrodes are positioned on the same side of the dielectric; in this case the electrostatic field between them is generally known as a 'stray' or 'fringe' field. For industrial application, the applied voltage of the order of 15,000 volts supplied by an electronic generator alternates at frequencies of some millions of cycles per second.

The amount of heat generated in the dielectric is determined by the frequency, the square of the applied voltage, the dimensions of the object and a physical property of the material termed 'loss factor' and is represented by the equation :

Power = $1{\cdot}41\ E^2\ f.F.\ \frac{A}{t} \times 10^{-15}$ kW.

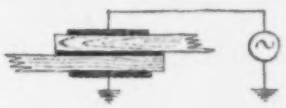
Where E = applied voltage,
f = frequency, F = loss factor.
A = area of the dielectric in square inches.
t = thickness of the dielectric in inches.
F, the loss factor, is itself equal to the expression K Cos Ø in which :
K = the dielectric constant of the material,
Cos Ø = the dielectric power factor of the material.

Therefore, 'loss factor' is a property of the material and a measure of the ease with which it can be heated by this method. Like other physical properties, it varies considerably for different substances. The equation shows that the heat generated in a dielectric is proportional to its loss factor, but the rate of rise of temperature will also depend upon its specific heat and density. The following table gives approximate values of the dielectric constant, power factor and loss factor of a few typical dielectric materials for frequencies around a million cycles a second.

MATERIAL	DIELECTRIC CONSTANT	POWER FACTOR	LOSS FACTOR
Natural Rubber	2·9	0·02	0·058
Oak, dry	3·3	0·04	0·132
P.V.C.	5·3	0·06	0·318
Nylon	3·7	0·05	0·185
Water, pure	80·0	0·03	2·40
Water, tap	80·0	0·5/5·0	40/400

The high loss factor of water means that materials which are difficult to heat when completely dry will often heat efficiently when moisture is present. The voltage must be increased towards the end of the process in some cases to remove the final moisture traces, the reduction in loss factor as the material dries out providing a safeguard against overheating.

If the workpiece is made up of a number of materials, each material will heat up uniformly but each at a rate depending upon its loss factor, thermal properties and density. The degree of temperature uniformity throughout the workpiece will then depend upon the extent to which thermal conductivity can equalise different rates of heating.



Such different rates of heating can be turned to good account in certain applications. For example, in wood glue setting, the glue lines heat up much more rapidly than the wood pieces being joined and the glue sets before the wood heats up substantially, wood having a lower loss factor than glue.

For further information get in touch with your Electricity Board or write direct to the Electrical Development Association, 2 Savoy Hill, London, W.C.2. Tel : TEMple Bar 9434.

Excellent reference books on electricity and productivity (8/6 each, or 9/- post free) are available — "Induction and Dielectric Heating" is an example.

E.D.A. also have available on free loan in the United Kingdom a series of films on the industrial uses of electricity. Ask for a catalogue.

6776/4

NEWS

GAS AT WORK IN INDUSTRY

SOME OF THE MANY applications of gas in industry were shown in an exhibition at the Royal Horticultural Hall, Westminster, this month. The exhibition, the second of its kind, was sponsored by four of the 12 Area Gas Boards and included a range of equipment, much of which was in operation. The demand for gas is apparently high in industries where processes are continuous and precise control is essential; a central feature showed examples, in the form of models and pictures, of the part gas plays in the development of modern industry.

On the heat-treatment stand, **British Furnaces Ltd.** were exhibiting their new gas-fired shaker-hearth furnace, which is capable of giving light case treatment or surface carbon correction. The furnace, fabricated in mild steel, is cylindrical, with integral support legs and base for the shaker mechanism. It is lined with hot-face insulation brick and backed up by diatomaceous earth designed to give the minimum thermal capacity and minimum radiation losses. The burner equipment was made up of 10 low-pressure, tangentially disposed tunnel burners of the new short-flame design and mounted in removable H.R.I. carriers, each with a premix pilot burner for safety when lighting up. The work to be treated is introduced to the furnace by means of a tray activated by a 4-in. bore air cylinder which has separate forward and backward speed adjustment and a frequency adjustment.

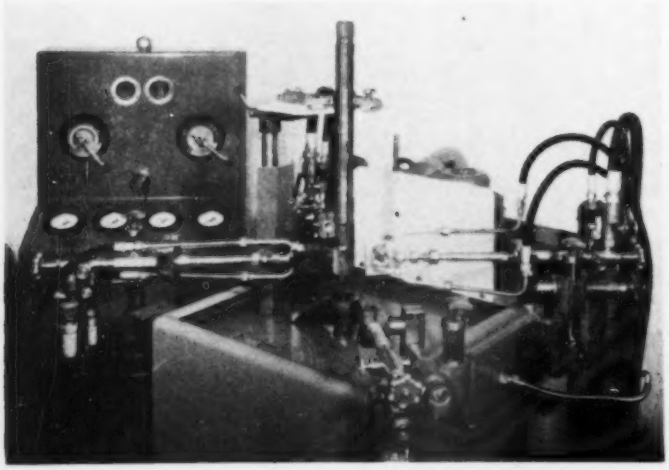
Shown in conjunction with the furnace was the MRX atmosphere generator. The gas atmosphere is generated by the endothermic reaction of air-gas mixture heated externally in a tube containing a catalyst, and the atmosphere so produced is suitable for bright annealing and clean hardening of low- and medium-carbon steels without scale or decarburization.

A rotary retort carburizing and carbonitriding furnace was also on show on this stand exhibited by **Thermic Equipment & Engineering Co. Ltd.** The furnace was having its first appearance at an exhibition and was shown complete with all flow gauges, giving process control for clean hardening, gas carburizing or carbonitriding. The makers claim that the unit provides a low-cost, controlled-atmosphere plant for treating steel components in batches, combining precise metallurgical control with high output. A special feature of the unit is that it does not require a separate generator to control case characteristics.

Dowson & Mason Ltd. exhibited a gas-fired continuous-wire-mesh conveyor muffle furnace which can be used in connection with the annealing and heat treatment of small pressings and similar components as well as brazing and sintering. Capable of an output of 80 lb./h. at a temperature of 800°C., the furnace is primarily intended for heat treatment in a prepared atmosphere and is used, for example, in the manufacture of radio valves. One of the particular advantages in using gas as a fuel in this furnace is that, as a result of the low sulphur content of town's gas, the life of the muffle is greatly increased.

Another furnace having its first showing at an exhibition was the small continuous furnace, fired by incandescent tubes and used for the vitreous enamelling of badges and similar small enamelled ware, shown by the **Incandescent Heat Co. Ltd.** The outstanding feature of the furnace is the use of Jetubes, high recirculation tubes developed by the company. A mixture of gas and air is burned in a refractory-lined section of the tube and products of combustion leave this chamber at high velocity through a nozzle, entrain the hot gases already recirculating in the body of the tube, so building up recirculation. The system gives even heating throughout the whole tube and the makers claim very high heat-transfer rates and a much improved flexibility, working at temperatures between 550 and 830°C. This type of furnace is already being used for heating tinplate strip in the high speed, continuous annealing line at the Velindre works of the Steel Company of Wales Ltd.

On the flame heat-treatment stand, a cutting machine which can read pencil line drawings automatically without physical contact between tracer and drawing was displayed by **Hancock & Co. Ltd.** The Hancoline machine has been constructed to give a high degree of accuracy



Pedlinghaus fully-automatic oxy-town's-gas gear-hardening plant using the recently-developed spinning method. Machines are available for small sprockets up to gears of 5 ft. diameter and 10 in. tooth width. The spinning method demands a bulk gas supply of adequate capacity as the consumption rate is considerable

over the cutting area. Of the dual-carriage type, the top and bottom carriages are of box construction giving rigid protection to the moving parts and electrical equipment. The bottom carriage runs on heavy section rails ground to a tolerance of 0·001 in. The sides of the main rails are ground to a similar tolerance and are engaged by ball-bearing check rollers. A live axle couples one pair of bottom carriage wheels and ensures precise longitudinal motion. Check rollers are mounted where necessary on eccentric bushes to make adjustment of squareness easy. The burner equipment is the latest non-backfiring F.C. type with flexible tubing coupling the burner head to the trimming valves, and provision is made to enable additional burner assemblies to be fitted without any structural modification of the machine.

Probably the most important item in this machine is the scanning head which scans the line drawn on a specially treated piece of paper, to offset any variation in the drawn dimensions due to atmosphere and temperature effects on the paper, and sends photocell signals to the control cabinet. The amplified signals are then passed to the servo motor geared to the scanning head, which is free to rotate and equipped with a small spotlight for location and setting purposes.

Another useful feature which adds to the simplicity of this system is a prismatic device, an integral part of the scanning head. A calibrated dial is provided, enabling the width of cut to be made automatically by the machine. Thus the drawing required is the same size as the work piece, and the laborious task of making drawings specially dimensioned to compensate for width of cut is eliminated.

An exhibit that had a great deal of attention paid to it during demonstrations by **Surfard Ltd.** was the Peddinghaus fully-automatic, oxy-town's-gas gear-hardening plant, utilizing the recently perfected spin-hardening method. The complete cycle of operations is preset and ensures consistent and accurate results. It is available for hardening small gears and pinions up to 5 ft. diameter and 10-in. tooth width, to a predetermined depth below the roots of the teeth, and the makers claim great increases in strength together with a remarkable reduction in distortion. The basis of this process is the milliscope pyrometer which can follow the temperature rises during a much shortened heating time, without any appreciable time lag. It uses the principle of the incandescent lamp pyrometer by comparing the radiations of two bodies inside a certain wave band, one issuing from the object and the other from a calibrated incandescent lamp. The receiving element consists of a lead sulphide cell. The floor-to-floor time for a small spur gear of 8½ in. dia. and 4-in. tooth width is 4½ min., and on quenching the gear may be handled manually. Surfard Ltd. are the representatives for England.

A new conveyorized pre-heating and fusing plant of particular interest to manufacturing jewellers, enamellers and badge manufacturers was displayed by **Stewart Gill & Co. Ltd.** The design enables accurate control of time and temperature to be obtained and virtually eliminates trial and error methods.

Gas-heated panel units for infra-red radiation were shown by **Parkinson Cowan Industrial Products.** They can be used in the vertical position or inclined up to 45° in either direction and an average panel temperature of 650° is available over the whole radiant area of 4½ sq. ft.

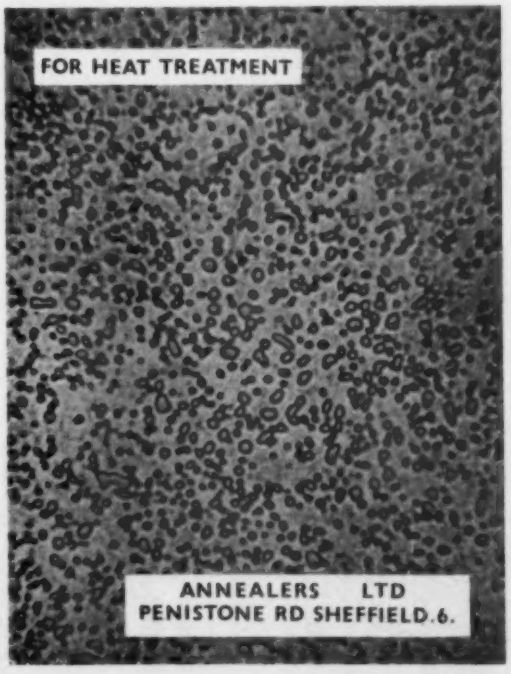
The ease of installation is claimed a feature of these tunnel units, each of which is complete in itself, and in most cases no additional frameworks or casings are necessary. The burners fitted are the neat-flame type and can be inspected while in operation and be removed for cleaning or adjustment from the rear of the unit without disturbing the assembly. The conveyor most used with these panels is of the monorail type which suspends the work to be treated and is speed-adjusted according to the process involved.

Air-blast tunnel burners and a gas-fired industrial batch-oven formed the exhibits of **Barlow-Whitney Ltd.** The oven was of the tray-loading type with air circulation with circular- and slot-discharge-type burners, electrically ignited and with 'Ether' flame failure equipment. An interesting feature of the oven was a safety relief panel of aluminium foil which blows out when the pressure builds up to a predetermined maximum.

An interesting demonstration was presented by **Fattorini & Sons Ltd.**, who produce badges and lapel emblems. Visitors were able to watch the enamelling and finishing of metal badges which included the cleaning and bright dipping of stampings, the application of the enamel, and its subsequent firing and glazing.

Gas exhibition at Harrogate

A northern 'Gas at Work in Industry' Exhibition, lasting five days, opens at Harrogate on March 28. Some of the exhibits are being taken from the London exhibition, but a wide range of new exhibits will be shown and the scope of the exhibition is being extended. The Harrogate exhibition is the first exhibition of its type to be held in the provinces, and emphasis will be given to applications of gas which are specially applicable to the North of England.



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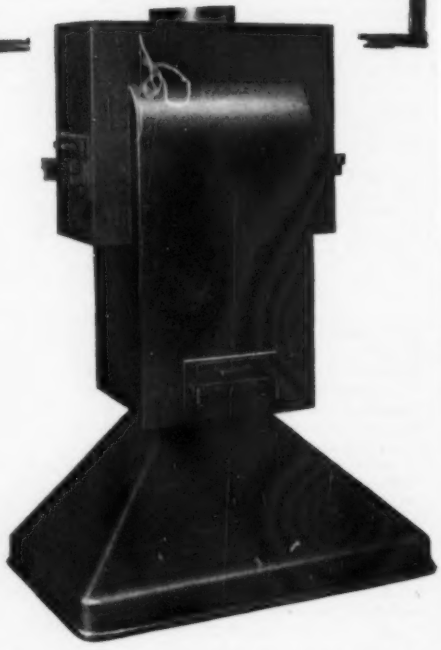

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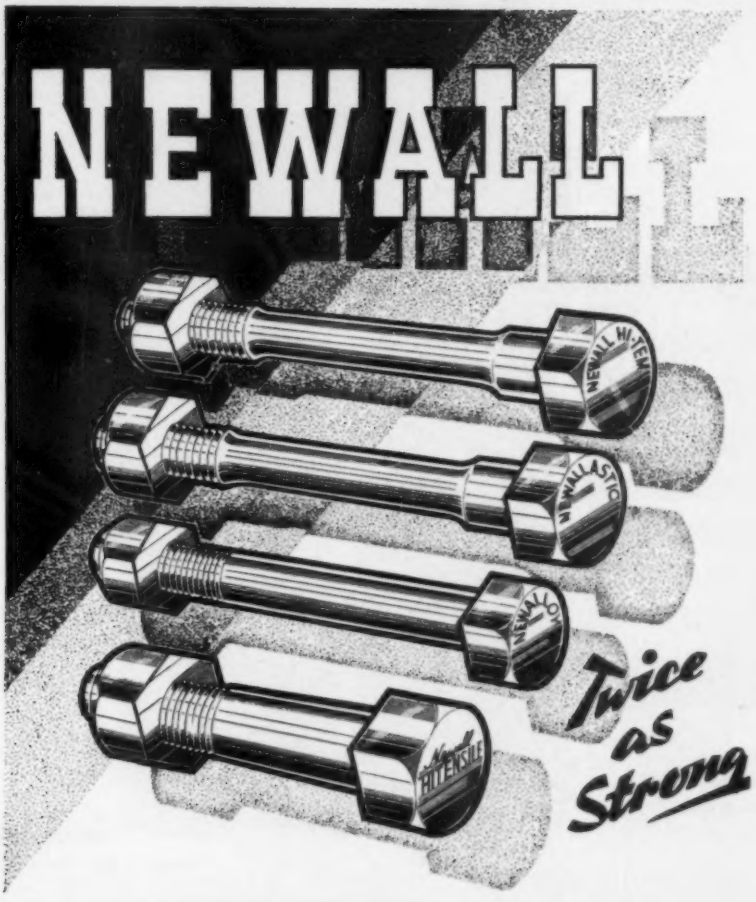

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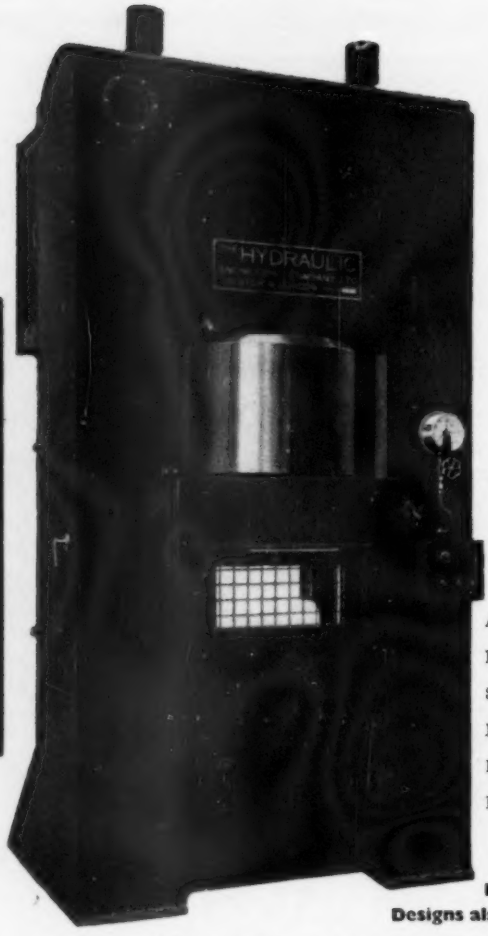

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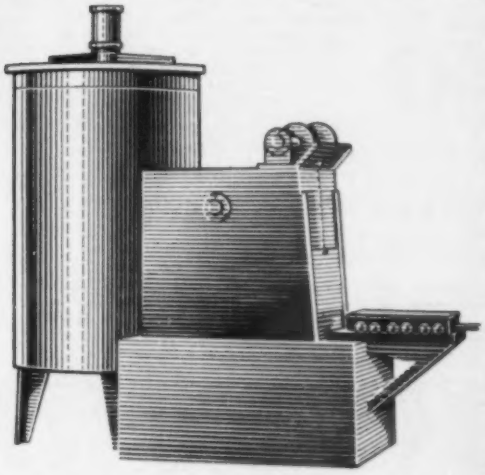

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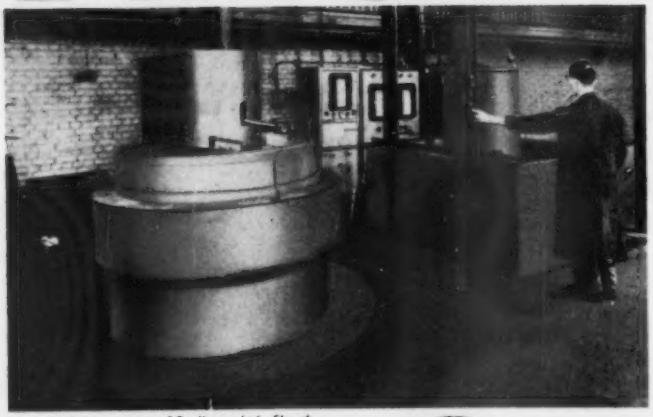

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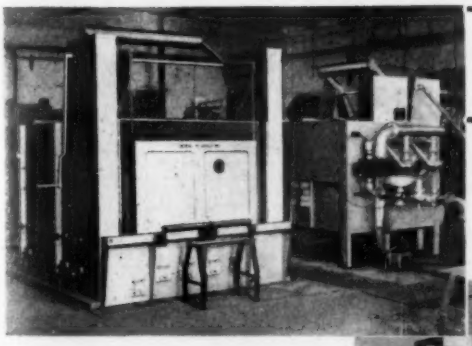

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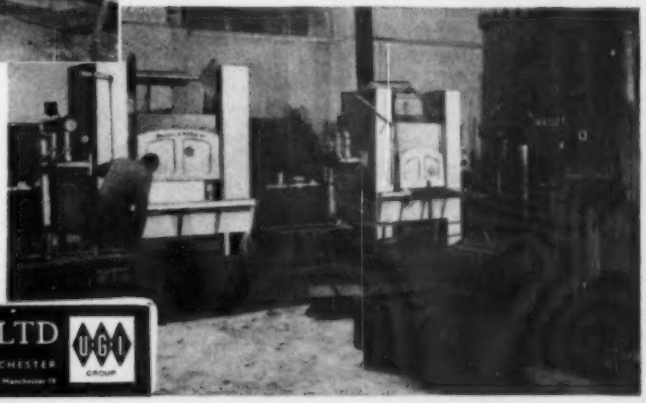

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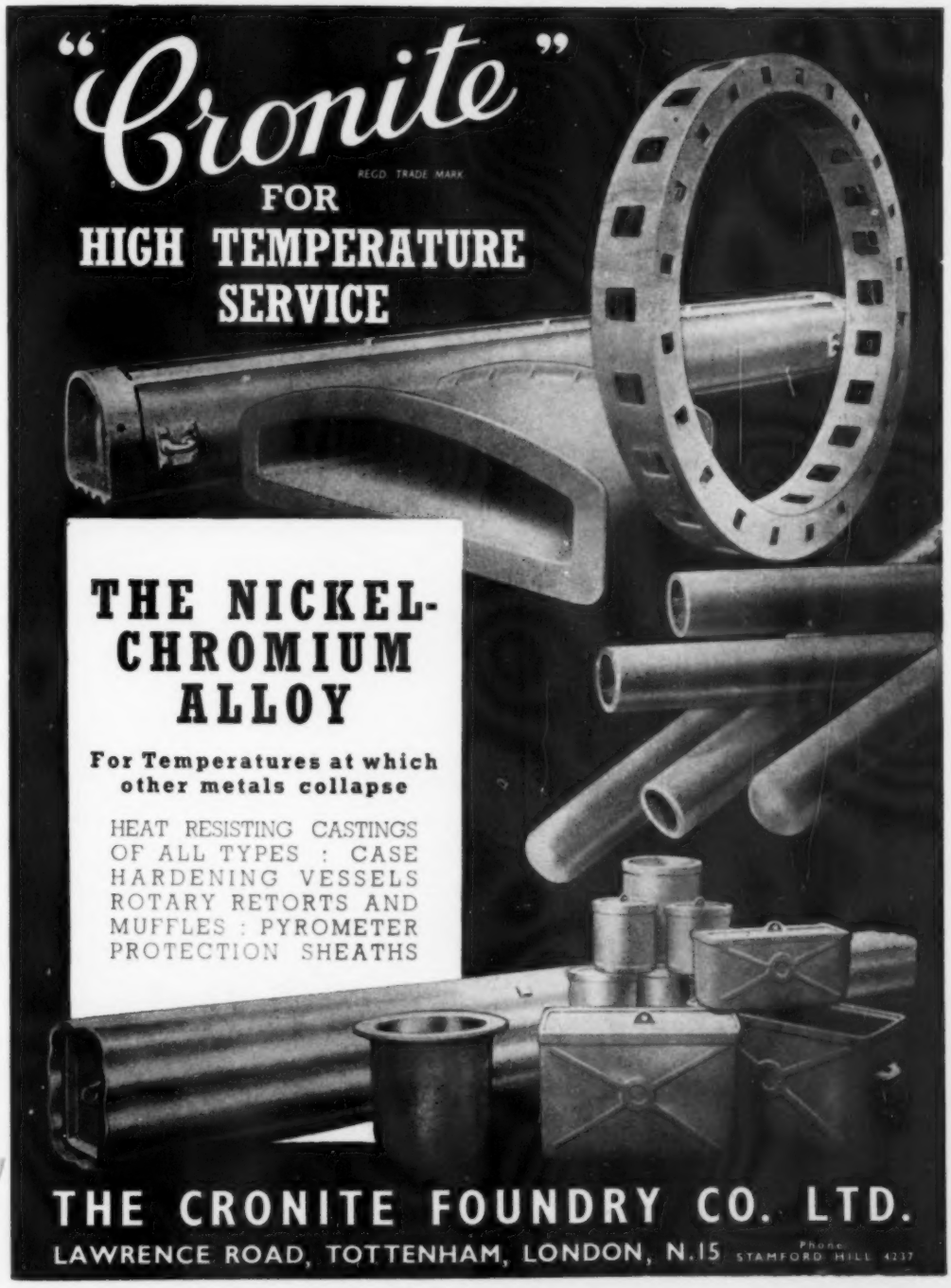
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